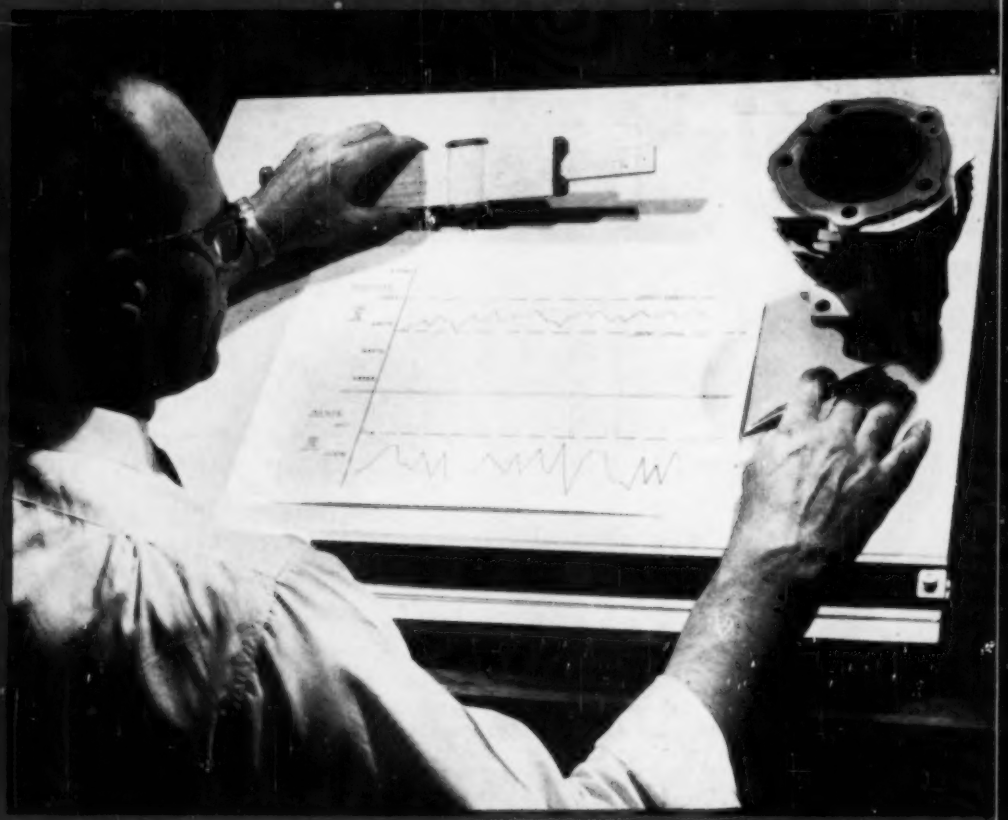
Industrial QUALITY CONTROL

NOVEMBER, 1952 VOL. IX, NO. 3



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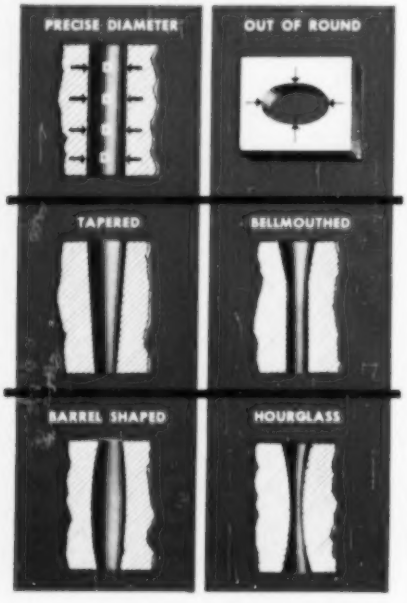

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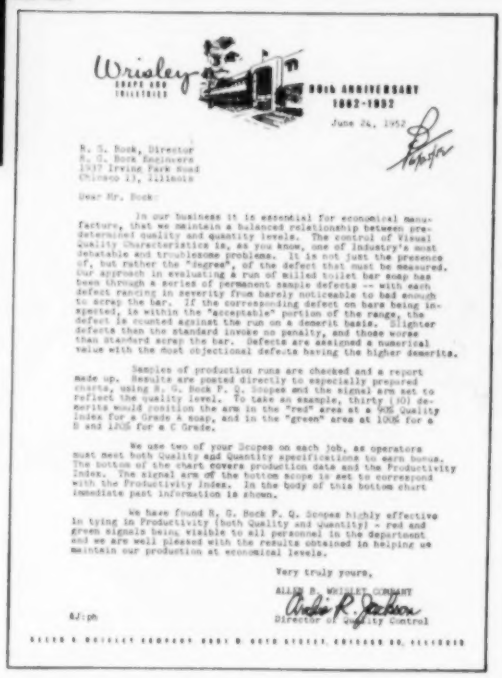

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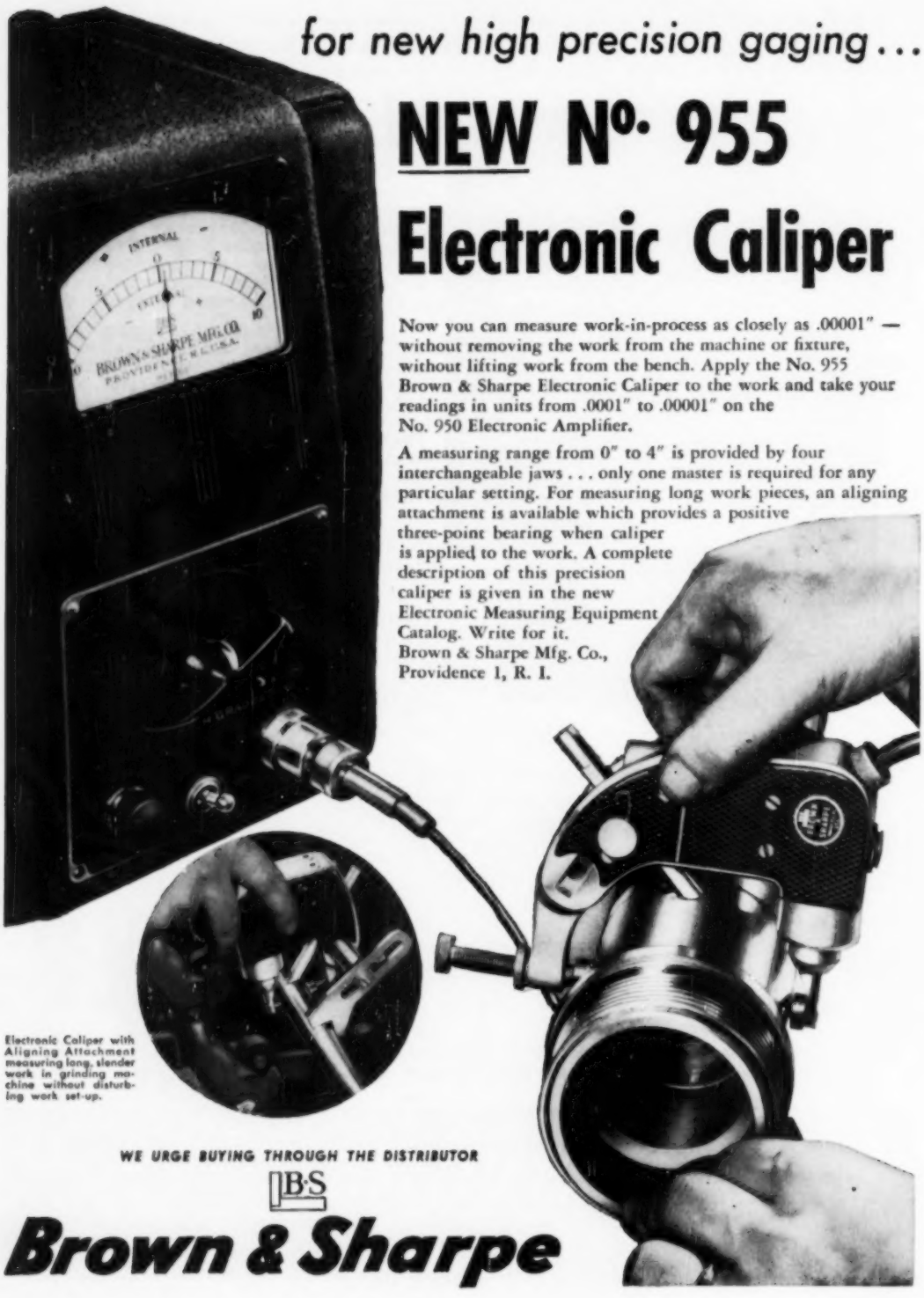

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Industrial Quality Control

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GREETINGS

In spite of the currently dubious connotation of the title word, it was my intention that you interpret it only in its purest meaning. Since this is the first issue of IQC coming out with the assistance of your new managing editor, I thought this would be a good opportunity for a brief personal chat to help us get acquainted.

Magazines in general and editors in particular, and even more particularly the attitudes arising from the periodic routines associated with publishing, often tend to become excessively stilted and formalized. This is a logical reaction, resulting from the conditioning necessary to meet schedules and deadlines, but is one that must be guarded against.

This, after all, is your magazine. It is sponsored by you, a member of ASQC, to be a real service to you, the reader. To be such a service, it must satisfy the needs and desires of the majority of you, and at the same time pay due regard to the interests of various minorities. In other words, if you are to receive the greatest service from your magazine, it must be run with the "consent (and suggestions) of the governed," so to speak. Therefore if, and when, you receive a questionnaire or a request for comments from us, please understand that we're not really trying to annoy you, but merely attempting to get an idea of how to serve you best.

In the past, your editorial chairman, Mason E. Wescott, has done much to achieve this aim. As your new managing editor, I should like to assure you that not only do I second this attitude, but I certainly hope that I shall have even more of an opportunity to fulfill it. I don't mean to imply that this aim, if once gained, is t h e r e b y consolidated. Achieving maximum service to you, the reader, is accomplished only by keeping in a pliable state those things which cater to your changing needs and desires. Be assured that I shall do my best to cooperate with you and the society officers in attempting to keep your magazine in such a condition that it is really useful to you.

After these words it is almost redundant to e c h o your editorial chairman's oft repeated idea that I will greet with open arms and mind all comments from you about any phase of the magazine operation.

G.R.F.

ERRATA

In the list of local section officers published in the October IQC News Supplement, G. A. Helberg, Maytag Co., was erroneously listed as the National Director for the Iowa Section. The National Director for this section is F. J. Halton, Deere & Co.

In addition, the names of several of the section officers were necessarily omitted from that list. Those of the National Directors are given on page 48; the others will be published as soon as they are available.

COVER PICTURE

We are indebted to Harley-Davidson Motor Company, Milwaukee, for our November cover picture.

Harold Klemm, chief inspector, has just plotted the results of a sample of cylinder bore measurements, and found the process "on the beam."

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Correspondence is invited on all controversial matters.

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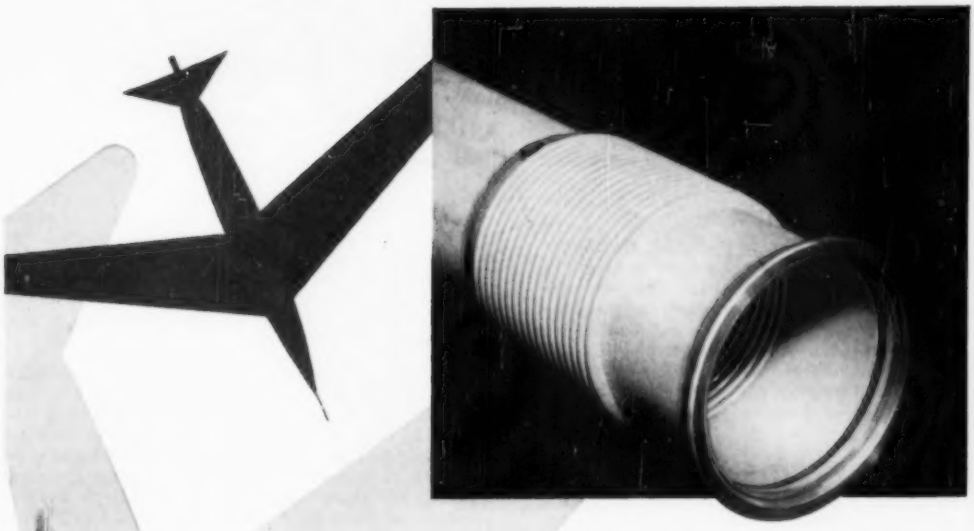

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Circular Probability Paper

FRED C. LEONE CHESTER W. TOPP

Case Institute of Technology

INTRODUCTION

This paper gives a description of circular probability paper, its construction and use, and several examples in which it is used to compute probabilities. For those who are not interested in the theoretical basis for the construction of the paper, a convenient starting place might be at the section on illustrations. For data used in some of the examples, the authors wish to thank The American Steel and Wire Company, Cleveland, Ohio, and The Aluminum Company of America, Pittsburgh, Pennsylvania.

DESCRIPTION

During World War II, H. H. Germond designed a graph paper for computing probabilities in the circular normal case. This paper was designed while Dr. Germond was on the Applied Mathematics Panel and was given the name, *Circular Probability Paper*. The existence of this type of graph paper is not widely known nor is it being published so far as the authors are aware. Mention of its use is made by Morse and Kimball,[1] and an informal demonstration of the paper and its use was given by the authors in connection with the *Seminar on Operations Research* held at Case Institute of Technology in the fall of 1951. Since it is believed that no note on its use has received general circulation, this article discusses briefly its construction and applications.

The problem is that of finding the volume under the surface

$$z = \frac{1}{2\pi} e^{-\frac{1}{2}(x^2 + y^2)} \tag{1}$$

above a region R in the xy-plane. Further, if two independent variables x and y have a joint distribution function given by (1), the problem is equivalent to asking the probability that pairs of values (x,y) lie in the region R. Introducing cylindrical coordinates (z,r,θ), the normal surface given by (1) becomes

$$z = \frac{1}{2\pi} e^{-\frac{1}{2} r^2} \tag{2}$$

and the volume under it above a circle of radius r with center at the origin is given by

$$V = \frac{1}{2\pi} \int_0^r \int_0^{2\pi} e^{-\frac{1}{2} r^2} \, r \, d\theta \, dr \tag{3}$$

Evaluation of (3) is immediate, giving

$$V = 1 - e^{-r^2/2} \tag{4}$$

If, in (4), we assign various values to V, we may solve for r and thus find the radius of the circle above which the volume is the assigned value of V. Thus, if V = 0.001 cubic units, r = 0.04472 units; if V = 0.008 cubic units, r = 0.12673 units; and if V = 0.021 cubic units, r = 0.20601 units. Reference may be made to Fig. 1 where the circles of radii 0.04472, 0.12673, 0.20601, etc. are drawn. The ring between the first and second circle is divided into seven equal parts, thus making the volume above each part equal to 0.001 cubic units. The ring between the second and third circle is divided into 13 equal parts so as to again make the volume above each part equal to 0.001 cubic units. Continuing in this way, circular probability paper is constructed.

Speaking in terms of probability, the probability that the pair (x,y) lie in any one cell is 0.001. The cells are thus referred to as cells of equal probability although, as may be observed in Fig. 1, the probability associated with the outer cells is not 0.001. The unit used in (1) is, in this interpretation, the common standard deviation of the variate x and the variate y. Thus, r being given above by 0.04472 means that r is 0.04472 standard units. The radii of the circles within which the probability is given by 0.1, 0.2, 0.3, etc. are indicated on the graph in Fig. 1, and various useful scales are shown at the bottom.

To make use of circular probability paper, the joint distribution of the variates x and y must be changed into the form (1) by an appropriate transformation of variables. The boundaries of the original region R for which a probability is sought are, of course, modified by the same transformation. The boundaries applying to the distribution (1) are then drawn on the graph and the number of dots falling within the boundaries are counted. The number of dots is next multiplied by the appropriate probability figure associated with the cells in which the dots occur. A dot which falls on a boundary line may be taken as half a dot. The answer arrived at is the approximate probability of an (x,y) value lying within the drawn boundaries. Examples of this procedure are given below.

ILLUSTRATIONS

Case 1. Historical Problem

Example 1. Consider as the first illustration the type of problem which lead to the construction of circular probability paper. Suppose a bomber is to drop a bomb upon a given target. In delivering this missile some error will be involved. This error may be made up of two components: (1) a range error which is parallel to the direction of flight and (2) a defiection error which is perpendicular to it. Suppose that the standard error of the range is 500 ft and that of the deflection is also 500 ft. Assume further that the target is 600 by 800 ft and that the point of aim is the center of gravity of this rectangle. What is the probability of hitting the target with a single bomb drop?

The solution can be obtained by proceeding as follows:

(1) Change the dimensions of the target to standard units

(2) Construct the target on the graph by measuring off the units on the sigma scale

[1] *Methods of Operations Research*, John Wiley and Sons, New York

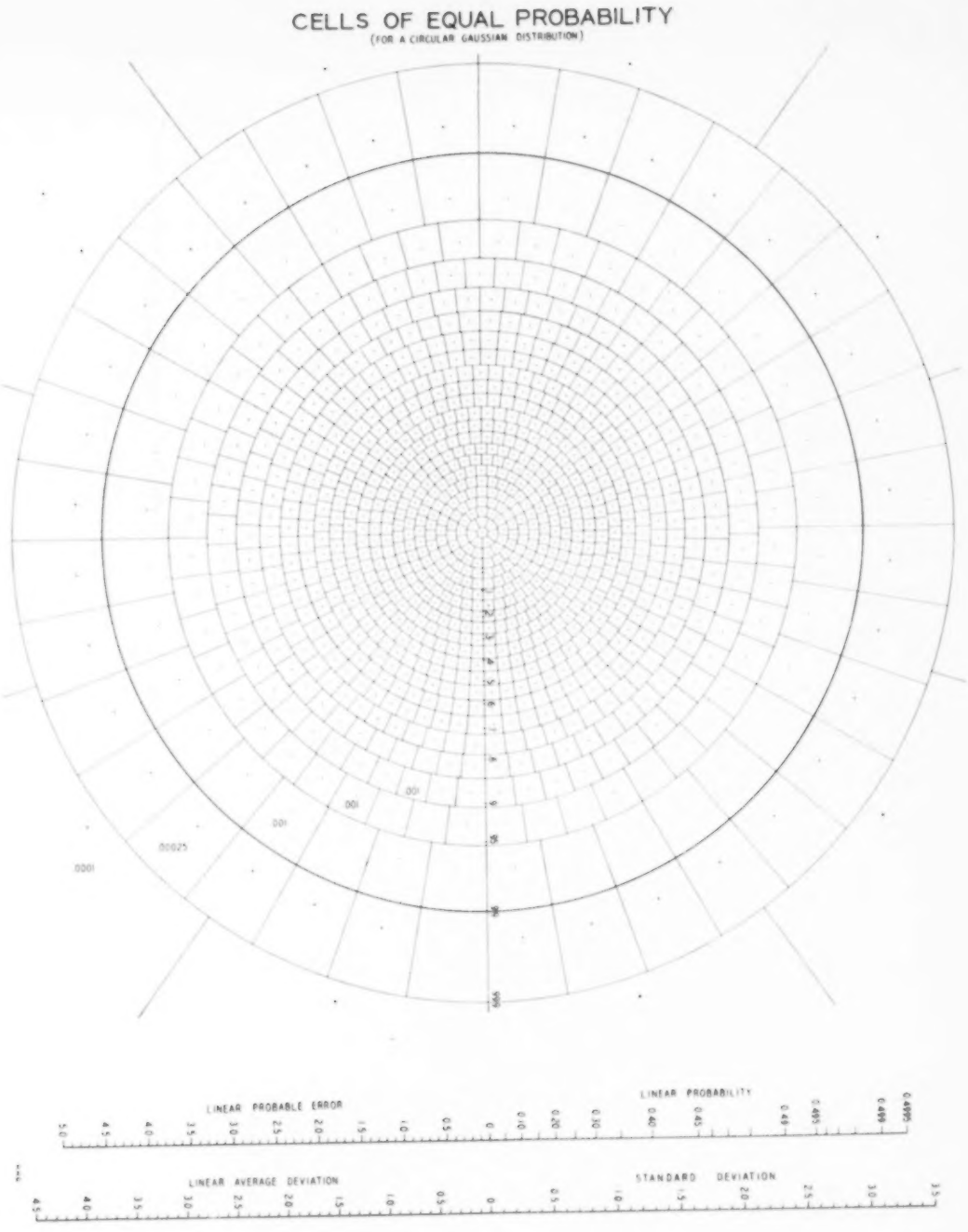

Figure 1—**Sample of Circular Probability Paper**

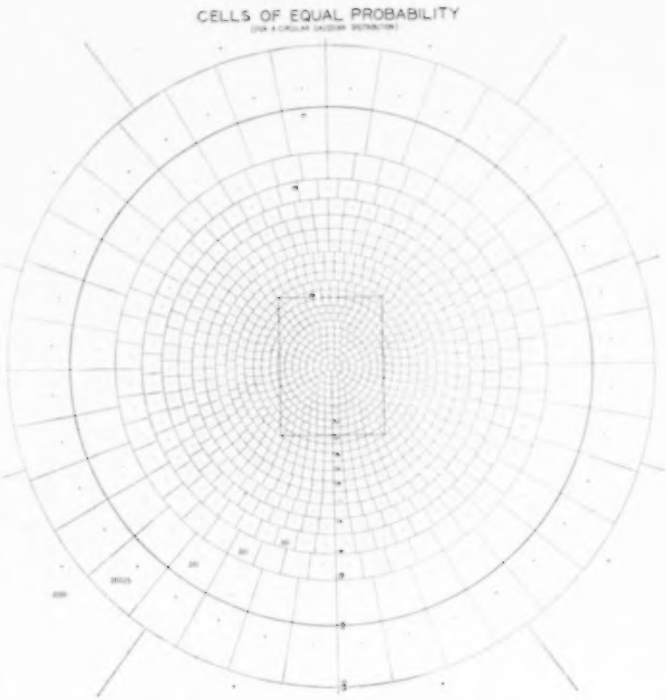

Figure 2—**Probability of Hitting Rectangular Target**

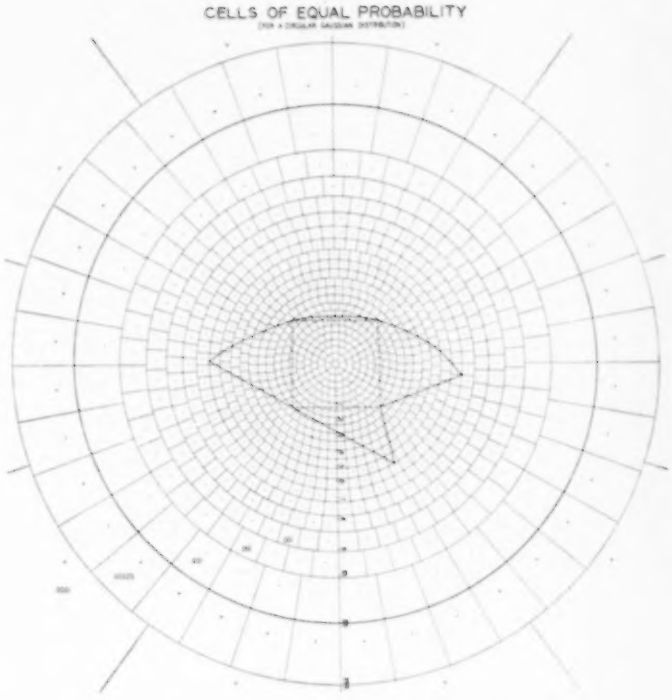

Figure 3—**Probability of Hitting Irregular Target**

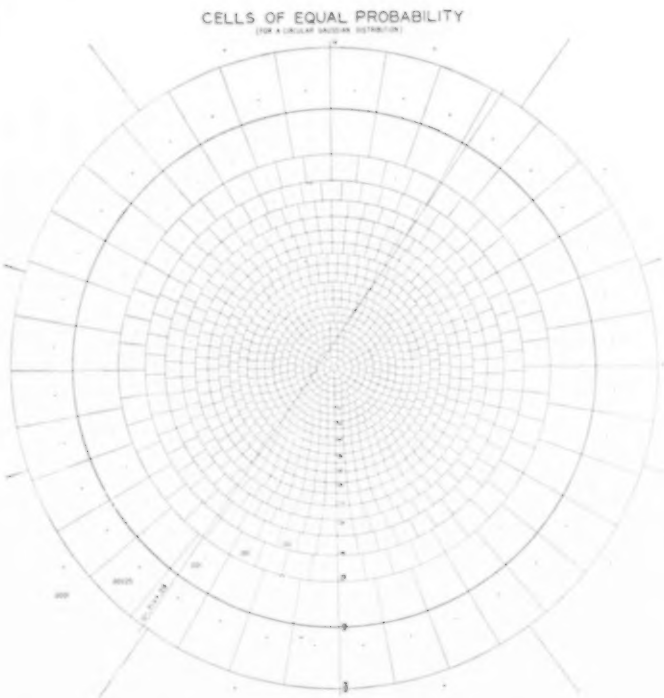

Figure 4—**Probability that Random Fit Is Satisfactory (Example 3)**

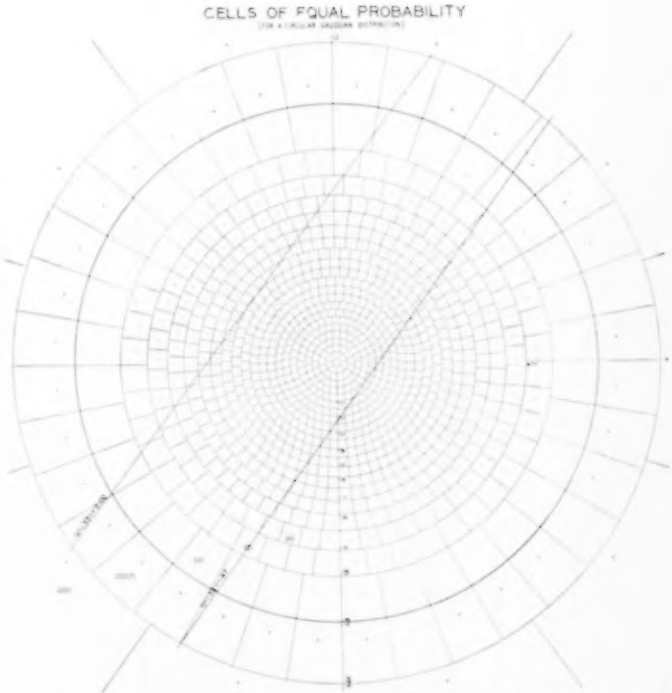

Figure 5—**Probability that Random Fit Is Satisfactory (Example 4)**

(3) Draw the rectangle in standard units with the center of gravity at the center of the graph

(4) Count the dots within the rectangle and give each a proper weight of 0.001, 0.00025, or 0.0001. The sum of these weighted dots is the answer.

Carrying out the above steps, we have

(1) The dimensions of the rectangle are 1.2 by 1.6 standard units.

(2, 3) The rectangle with center of gravity at the center of the graph is shown in Fig. 2.

(4) There are 258 dots of weight 0.001, and none of weight 0.00025. The probability P of hitting the target with a single bomb drop aimed at the center of gravity is then

$$P = 0.258$$

Example 2. The problem of Example 1 can also be solved by other methods. Suppose, however, that the target were irregular. The method given above can easily be applied to solve the problem. The method would first require the estimation of the radii from the center of gravity in standard units. If, in the above problem, the target were irregular rather than rectangular, we need only to construct it in standard units, as in Fig. 3. Finally, for a good approximation to the probability of a hit, it is necessary to count the dots within the target boundaries and give them the proper weight. Fig. 3 shows the target in standard units. For comparison, a 500 by 500 ft square constructed in standard units is also shown in dotted lines on the same figure. The probability of hitting the irregular target is 0.306.

Case 2. Bivariate and Uncorrelated

Example 3. Consider now an interference problem where a circular sleeve is forced into a hole which is a circular cylinder. The sleeve is to have an outer diameter greater than the inner diameter of the hole. However, the specifications on the interference must be such that the fit is within appropriate limits. If the interference specifications are 0.001 to 0.005 in., what is the probability of the specifications being met when a sleeve is matched with a hole at random?

Since the parts are manufactured independently, the distribution can be considered as uncorrelated. Suppose the following parameters were obtained:

OD of sleeve:	$\bar{x} = 2.587$ in.,	$\sigma_x = 0.0015$
ID of hole:	$\bar{y} = 2.585$ in.,	$\sigma_y = 0.0020$

The probability of a satisfactory random fit is given by

$$P = \frac{1}{2\pi\,\sigma_x\sigma_y}\int_{-\infty}^{\infty}\int_{y+.001}^{y+.005} e^{-\frac{1}{2}\left[\frac{(x-\bar{x})^2}{\sigma_x^2}+\frac{(y-\bar{y})^2}{\sigma_y^2}\right]}\,dx\,dy \qquad (5)$$

The integrand is changed into the form (1) by the transformation of variables

$$\frac{x-\bar{x}}{\sigma_x} = u$$

$$\frac{y-\bar{y}}{\sigma_y} = v$$

The probability in (5) then becomes

$$P = \frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{\frac{\sigma_y}{\sigma_x}v+\frac{y-\bar{x}}{\sigma_x}+\frac{.001}{\sigma_x}}^{\frac{\sigma_y}{\sigma_x}v+\frac{y-\bar{x}}{\sigma_x}+\frac{.005}{\sigma_x}} e^{-\frac{1}{2}(u^2+v^2)}\,du\,dv$$

Substituting the values of the parameters in the upper and lower limits of the inner integral gives the lines to be drawn upon the circular probability paper as

$$u = 1.33v + 2.00$$

$$u = 1.33v - 0.67$$

These lines are shown in Fig. 4. The probability P is obtained by counting the dots between these lines and attaching the appropriate weights to them. We find that P = 0.538.

Example 4. A compressor blade is ground to give an interference fit of 0.0005 in. to 0.002 in. over the slot size for a compressor band. In grinding the blades, the mean is given by $\bar{x} = 0.85358$ in. and the standard deviation by $\sigma_x = 0.00017$. In broaching the bands, $\bar{y} = 0.85313$ in. and $\sigma_y = 0.00012$. The compressor band dimension is to lie between 0.8520 and 0.8540 in.

Now we want to know the probability that a satisfactory fit is obtained if a blade is matched with a band at random. This probability is given by

$$P = \frac{1}{2\pi\,\sigma_x\sigma_y}\int_{.8520}^{.8540}\int_{y+.0005}^{y+.002} e^{-\frac{1}{2}\left[\frac{(x-\bar{x})^2}{\sigma_x^2}+\frac{(y-\bar{y})^2}{\sigma_y^2}\right]}\,dx\,dy \qquad (6)$$

Making the transformation of variables as in the preceding example, (6) becomes

$$P = \frac{1}{2\pi}\int_{-9.42}^{7.25}\int_{.71v+.29}^{.71v+9.12} e^{-\frac{1}{2}(u^2+v^2)}\,du\,dv$$

The four lines given by the four limits are graphed on circular probability paper. All of the lines except $u = 0.71v + 0.29$ are off the paper, the line $u = 0.71v + 9.12$ being off at the top. The graph is shown in Fig. 5, where the probability may be read off by counting the dots above the line and attaching an appropriate weight to them. We obtain P = 0.432.

This type of problem might also arise in the manufacture of storm windows where an insert and a frame are manufactured separately and the insert must fit within the frame. In fact, this type of problem may arise in any fitting or interference problem where the two parts are manufactured independently.

Example 5. In this problem a mechanical property comparison of an aluminum alloy extrusion is considered. The properties to be compared are the longitudinal and transverse tensile strength in psi of the test bars. The longitudinal strength is determined by testing the piece with the axis of the test specimen parallel with the direction of extruding, and the transverse strength is determined by testing with the axis of the specimen normal to the direction of extruding. The correlation coefficient is not significantly different from zero. Hence in the range studied the two strengths can be considered independent. The estimates of the parameters are

	Longitudinal	*Transverse*
Mean	$\bar{x} = 74{,}825$ psi	$\bar{y} = 70{,}155$ psi
Standard Deviation	$\sigma_x = 2641$	$\sigma_y = 3962$

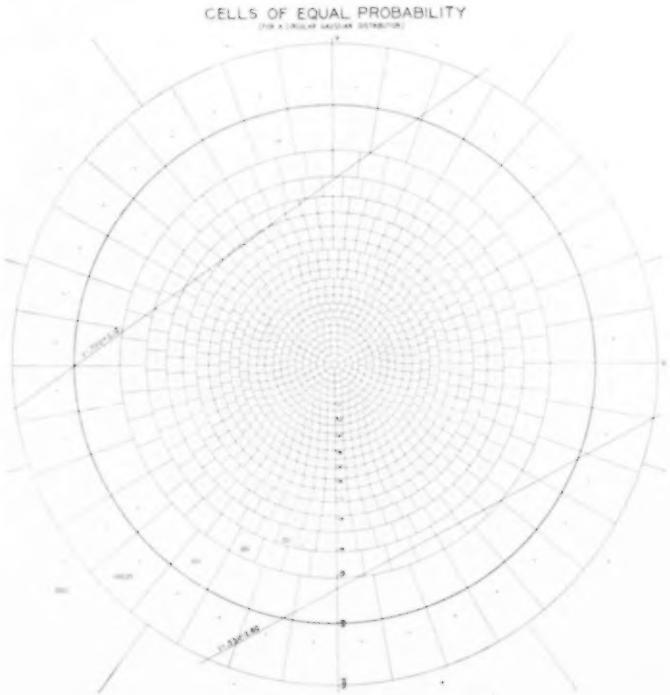

Figure 6—**Probability that Transverse Tensile Strength Lies Between 80% and 105% of Longitudinal Tensile Strength**

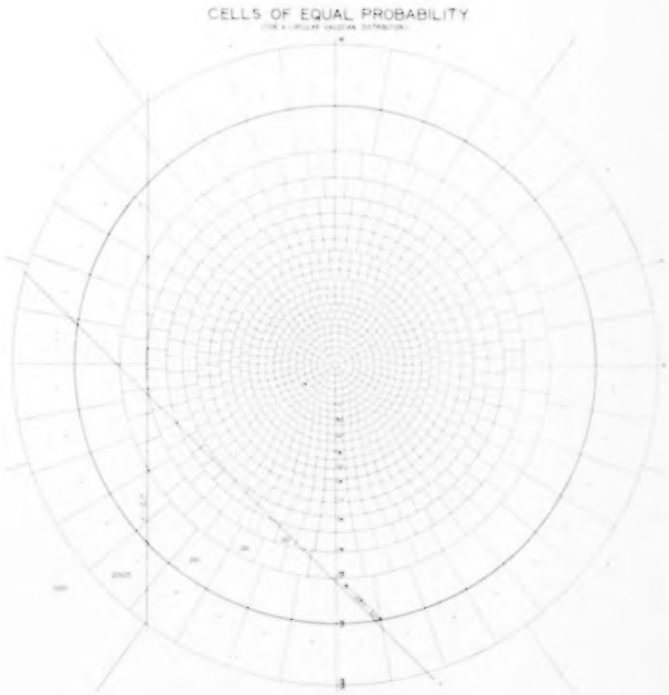

Figure 7—**Probability that Yield Strength and Tensile Strength for No. 12 Gage Wire Will Be Greater than 175,000 and 200,000 psi, Respectively**

We wish to know the probability that y, the transverse strength, lies between 0.80x and 1.05x, where x is the longitudinal strength. This probability is given by

$$P = \frac{1}{2\pi\,\sigma_x\sigma_y}\int_{-\infty}^{+\infty}\int_{.80x}^{1.05x} e^{-\frac{1}{2}\left[\frac{(x-\bar{x})^2}{\sigma_x^2}+\frac{(y-\bar{y})^2}{\sigma_y^2}\right]}\,dy\,dx \qquad (7)$$

This can be reduced to a form suitable for use with circular probability paper by making the transformations of variables as in the preceding examples. The two lines to be graphed become

$$v = 0.70u + 2.12$$
$$v = 0.53u - 2.60$$

These lines are shown in Fig. 6. If we count the dots and give each the proper weight, we find that

$$P = 0.947$$

Case 3. Bivariate Normal with x and y correlated.

Example 6. Let us now consider a case where x and y are not independent. Table 1 is a double-entry table of Yield Strength versus Tensile Strength of No. 12 gage wire. The distribution is a bivariate normal with the estimate of the parameters equal to the following:

	x — Yield Strength	*y — Tensile Strength*
Mean	$\bar{x} = 188{,}700$ psi	$\bar{y} = 215{,}000$ psi
Std. Dev.	$\sigma_x = 6300$	$\sigma_y = 6900$

Correlation Coefficient $r = 0.70$

Suppose we wish to find the probability that YS will not be less than 175,000 psi and that TS will not be less than 200,000 psi. If we were to attempt this by calculus (and this would be a laborious task), the equation for this probability would be

$$P = \frac{1}{2\pi\,\sigma_x\sigma_y\sqrt{1-r^2}}\int_{200.000}^{+\infty}\int_{175.000}^{+\infty} e^{-\frac{1}{2(1-r^2)}\left[\frac{(x-\bar{x})^2}{\sigma_x^2}-2r\frac{(x-\bar{x})(y-\bar{y})}{\sigma_x\sigma_y}+\frac{(y-\bar{y})^2}{\sigma_y^2}\right]}dx\,dy \qquad (8)$$

To reduce the integrand to the form (1), first make the transformation of variables

$$u = \frac{x-\bar{x}}{\sigma_x}$$

$$v = \frac{y-\bar{y}}{\sigma_y}$$

so that (8) becomes

$$P = \frac{1}{2\pi\sqrt{1-r^2}}\int_{\frac{200.000-\bar{y}}{\sigma_y}}^{+\infty}\int_{\frac{175.000-\bar{x}}{\sigma_x}}^{+\infty} e^{-\frac{1}{2(1-r^2)}\left[u^2-2ruv+v^2\right]}du\,dv \qquad (9)$$

Now, making a second tranformation

$$w = \frac{u-rv}{\sqrt{1-r^2}}$$

(9) becomes

$$P = \frac{1}{2\pi}\int_{\frac{200.000-\bar{y}}{\sigma_y}}^{+\infty}\int_{\frac{175.000-\bar{x}-r\sigma_x v}{\sigma_x\sqrt{1-r^2}}}^{+\infty} e^{-\frac{1}{2}(w^2+v^2)}\,dw\,dv \qquad (10)$$

TABLE 1—Distribution of Tensile Strength Versus Yield Strength for No. 12 Gage Wire

x = Yield Strength, in 10^3 psi

y = Tensile Strength, in 10^3 psi	165-167	168-170	171-173	174-176	177-179	180-182	183-185	186-188	189-191	192-194	195-197	198-200	201-203	204-206
190-192	1													
193-195														
196-198					1	2	2			1				
199-201					2	1		1						
202-204				1	1	2	2	1						
205-207				1	3	8	9	4	1					
208-210			1			4	9	5	2	3				
211-213				2	1	7	10	16		1				
214-216					2	2	12	27	20	13	1	1		
217-219					1	1	2	12	11	10	6	3		
220-222							1	1	3	11	15	6		
223-225							2		1		9	5	3	
226-228							1	1		1	1	5	1	
229-231						1							1	1
232-234											2			
235-237													1	

Substituting in the values of the parameters, gives

$$P = \frac{1}{2\pi}\int_{-2.17}^{+\infty}\int_{-.98v-3.04}^{+\infty} e^{-\frac{1}{2}(w^2+v^2)}\,dw\,dv$$

The two lines

$$v = -2.17$$
$$w = -.98v - 3.04$$

are shown in Fig. 7. The probability P is obtained by counting dots in the region to the upper right and is seen to be 0.953.

CONCLUSION

Circular probability paper can be of great assistance in solving some industrial problems in probability which hitherto were prohibitive because of the extensive calculation involved. If we can assume that the pairs of values x and y are normally distributed, then this paper can be employed. Independence is not necessary. Several illustrations of the use of this graph paper have been given. These illustrations may serve as models for using the paper in any case where two variables are normally distributed.

The Need for Statistical Quality Control in Engineering Education*

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STATISTICAL quality control in the large is more than control charts and acceptance sampling; it is the application of all statistical methods in the improvement of the manufacturing operation. In discussing the need for SQC in engineering education, I shall be using this broader definition. This in no way implies that I consider the study of the control chart and acceptance sampling techniques to be of little value to the engineer, but rather indicates my belief that the engineer needs a thorough understanding of statistical principles and that the Shewhart control charts and acceptance sampling are but two of the many valuable methods of handling quantitative information which have been derived from these principles. I consider that the study of control charts and acceptance sampling provides an excellent introduction to statistical philosophy, but I deplore the possibility that learning should stop without some slight acquaintance with the many other statistical tools which a considerable group of modern engineers are finding effective.

In the course of my discussion I should like to raise three closely related questions for your consideration and to enlist your aid in finding adequate answers.

HOW GREAT IS THE NEED FOR SQC IN THE EDUCATION OF THE ENGINEER?

In spite of the fact that the American Society for Quality Control has a current membership of about six thousand and in spite of other favorable signs of growth which I shall mention later, I feel that the increase in the number of engineers who appreciate statistical principles has been painfully slow. As a result of this pessimistic attitude I find myself wondering, from time to time, whether I am wrong in my conviction that any great general need exists. If time and money were available I should like to apply statistical principles in setting up an experiment to answer this question. And I believe that this should be done by some group in our society. However, for the time being, I must draw conclusions from a non-randomly selected set of references, noting that use in engineering work implies educational need.

A Bibliography of Statistical Quality Control—Supplement, compiled by G. I. Butterbaugh and published by the University of Washington Press in 1951, lists several hundred papers on statistical applications in the fields of aircraft engineering, ceramics, electrical engineering, physics, mechanical engineering, industrial engineering, naval engineering, analytical chemistry, metallurgy, and chemical engineering which have been published since 1946. In addition to those papers concerned mainly with control charts and acceptance sampling, there are many where the use of tests of significance, analysis of variance, bivariate and multiple regression, and rank correlation is indicated. It would be difficult to establish that the authors could not have obtained their results without the use of statistical methods, but there seems to be little doubt that engineers without statistics would have difficulty in reading the papers.

In January, 1951, the American Society for Testing Materials published an *ASTM Manual on Quality Control of Materials*, presumably for the benefit of its membership. Presentation of data, control charts and confidence limits are the topics covered.

Among titles listed in Movshin's bibliography section in the January, 1952, issue of IQC are "Microdetermination of Carbon and Hydrogen," "Further Examination of Reproducibility in Chemical Analysis," "Statistical Analysis of Blast Furnace Production Data." The listings in other issues confirm the use of statistical methods for research and development in diverse engineering fields and, therefore, the need for statistical education.

It seems useless to burden this paper with the weight of further evidence of this sort. It can be found by inspecting recent volumes of the official journal of almost any engineering society. For example, a paper (*Journal of Society of Glass Technology*, Vol. 33, No. 150, February 1949) by C. E. Gould, "The Solution of the Refractory Blocks in the Tank Wall of a Glass Melting Furnace," would prove to be unintelligible without some knowledge of statistics.

Writing on page six of their book on *Methods of Operations Research* (The Technology Press and John Wiley and Sons, 1951) Morse and Kimball remark,

> The final aim of operations research, of course, is to predict future operations and to understand them well enough so as to be able to modify them to produce new or better results.

(This sounds like the general aim of all engineering research.) They go on to say,

> The aim is not simply to record past operations or just to explain them; in this respect the work differs from the usual statistical analysis.

(I hope that this is also one way in which SQC differs from old-time statistical analyses.) Then, on the next page, they state,

> The most important single mathematical tool of operations research is probability and statistical theory.

This statement is especially gratifying because the authors are physical scientists, and a look at their bibliography suggests that they may not have been aware of all of the

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more recent work in statistical inference, experimental design, sequential analysis, etc., which has added so much power to the tool they commend so highly.

It is interesting to note that during the past few years several of the engineering societies have endorsed the existence of the need for statistics by sponsoring sessions or symposia on applied statistics for the benefit of their membership. These include the American Institute of Electric Engineers, American Society for Testing Materials, American Society for Metals, American Chemical Society, and American Society of Mechanical Engineers.

Before leaving this question of greatness of need, I might suggest that, perhaps, the extent of the need for the statistical view-point in engineering can best be measured by the engineers themselves. Perhaps the Committee on Statistics of the University of Chicago had this in mind in establishing a program of three awards per year to holders of the doctorate or equivalent in the biological, physical and social sciences. Quoting from their announcement:

> The purpose of the Awards is to give statistical training to a few scientists who may be expected to employ it both to the direct advance of their specialties and to the enlightenment of their colleagues and students by example, by consultation, and by formal instruction. The development of the field of statistics has been so rapid that problems of communication are a serious obstacle to its full exploitation. The amount and the quality of instruction available to students are constantly increasing, but there is a real need, which these Awards seek to fill, for making appropriate instruction available to already established scientific workers who give promise of immediate applications of statistics to their special fields.

WHY HAS THE EXISTENCE OF THIS NEED BEEN SO LONG IGNORED?

Dr. W. Allen Wallis, writing in the preface of *Techniques of Statistical Analysis*, McGraw-Hill 1947, suggests a possible answer when he says:

> The chemical, physical and engineering sciences are on the whole, distinctly backward in the statistical planning of experiments and the analysis of empirical data. . . . No doubt this is partly because physical scientists have attained a high degree of proficiency in experimental techniques and can make repeated, independent experimental investigations of a given phenomenon . . . so that competent investigators are likely to learn the truth (though perhaps belatedly and at excessive cost) despite crudities in statistical techniques.

A somewhat different explanation is offered by Dr. Walter A. Shewhart in his 1940 address on "Contributions of Statistics to the Science of Engineering" at the University of Pennsylvania Bicentennial Conference (Monograph B-1319, *Bell Telephone System Technical Publications*). In discussing the success of the applied scientist in contributing wonders for our enjoyment, Shewhart remarks:

> He has done much of this with a comparatively simple but extremely powerful tool; namely, scientific method based upon the concept of physical laws of nature that assume perfect or certain knowledge of a set of facts and then state exactly what will happen at any future time.

Shewhart states further,

> The fundamental difference between engineering with and without statistics boils down to the difference between the use of a scientific method based upon the concept of laws of nature that do not allow for chance or uncertainty and a scientific method based upon the laws of probability as an attribute of nature.

In many cases, engineering experimentation seems to take the following course: An experiment is conducted, a set of data is obtained, the data are summarized by computing and recording a statistic, such as the average.

The engineer does not realize, perhaps, that he has calculated a statistic because of lack of clear conception of the difference between universe and sample, parameter and statistic. Ordinarily he is content to report the value of the statistic calculated and leave to the reader the dangerous task of interpreting the experimental result. If the reader wishes to determine the limits of uncertainty for that universe parameter for which it is implied the sample statistic gives the exact value ("allowing for experimental error"), he is handicapped by a lack of exact definition of the universe sampled or the method of sample selection.

However, there are some extenuating circumstances because experimental results usually carry little weight until there have been further experimental verifications. A second scientist repeats the experiment and calculations, thus getting a new value for the statistic. Now we have two estimates for the parameter. If they are close together (and I confess ignorance of the objective definition of "closeness" in common usage here)—if they are "close" together, the results of the two investigations are assumed to be in agreement. The reader, at least, has a sample of two experimenters.

Many engineers have a curious attitude toward chance variation. For some reason they seem to consider its existence as an insult to engineering science. As near as I can interpret their attitude, they seem to believe that scientists ought to be able to isolate the exact causes of all variation and, since this goal of perfection has not been attained, there is a certain stigma attached to the presence of variability. Therefore, as in the case of the model child who has a temporary lapse of deportment and acts like a little beast, we should politely ignore all unexplained variation and just act as though it had not happened.

There are many good engineers and scientists, however, who are not ashamed to recognize that physical constants, determined theoretically from mathematical models of idealized situations, are not constants for the heterogeneous materials and conditions of our physical world. Since they cannot achieve complete determinism, they are willing to face facts and cope with the world as it is. For example, Dr. R. M. Haward writes on page 39 of his recent book on *The Strength of Plastics and Glass*, (Cleaver-Hume Press, London, 1949),

> It is at present impossible to predict the strength of a particular piece of glass, except within very wide limits, and only the average obtained from a large number of strength measurements has real meaning. However, even an average strength figure does not alone sufficiently characterize the property measured since it is also necessary to know the degree of scatter to be expected in the results; i.e., the extent to which individual measurements are likely to depart from the mean. Thus adequate measurements of the strength of glass are inseparable from the characteristics of statistical procedure and the full implications of this variability must be appreciated before any attempt can be made to apply the conclusions reached from experimental work.

If anybody should suspect that Haward is alone in his recognition of the central role to be played by

statistical principles in coping with variability or that troubles are confined to glass, he might read Chapter V of the monograph, *An Engineering Approach to the Selection, Evaluation and Specification of Metallic Materials* (Reprinted from *Steel*, November 22, 1943—February 14, 1944), prepared by Dr. H. W. Gillett, formerly Chief Technical Advisor at Battelle Memorial Institute. In his first paragraph he states that "scatter is the primary, underlying problem in the engineering use of materials" and then proceeds to illustrate how necessary the statistical viewpoint is for the practicing engineer. Two of his many observations which I find satisfying are,

> We are often told that the polished endurance limit of a steel, determined on smooth specimens, is half the tensile strength. But when thousands of endurance tests are plotted against tensile strength as in Fig. 22, the scatter band shows that this "law" is never wholly reliable, that it becomes still less reliable above 180,000 psi.

and

> The probability point of view leads to skepticism about statements in technical and advertising literature on the properties of material of a given chemical specification. Characteristic curves of tensile properties vs. tempering temperatures for various SAE steels have been published by various steel mills as guides to the user. In some cases the curves for the same SAE steel given by two producers differ more than those for two SAE steels of quite different chemistry. When scatter band curves are given instead of mere averages, these discrepancies become more understandable.

It is my considered opinion that the principal reason why the engineer has failed to recognize his need for statistics is because of this refusal to admit the existence of chance variation in nature. As long as, on the one hand, he insists on considering only "ideal" materials and, on the other hand, is content to lump together chance variation and experimental errors, I am not optimistic about any change in his attitude toward the need for statistical methods.

Another weighty reason is, perhaps, because most engineers have not had time to find out what modern statistics has to offer. The University of Chicago announcement, along with my past experience, leads me to issue this challenge to the engineer in any field: Spend one year in studying modern statistics. Try to apply the principles and methods to your own problems. Then prove publicly that your time and efforts were wasted.

Such a challenge is quite safe. Any worker in the field of engineering research, for example, will speedily become aware that in engineering experimentation, as is the case with all other types, the data observed represent a sample from a universe. He will appreciate that modern statistical inference provides the best objective methods for extracting the maximum amount of information from the sample regarding the universe which, after all, is his real interest. He will come to appreciate the truth of such a statement as that of P. O. Johnson, on page 386 of the June, 1951, issue of *Scientific Monthly*, when, in discussing statistics as a scientific method, he says,

> Scientific method is common to all the sciences. Statistics as a branch of the scientific method provides the doctrine of the planning of experiments and collection of other types of observations, and of interpreting their consequences. This common relation to all sciences is strengthened in that statistics furnishes a common methodological basis of understanding, namely, the derivation of the best infallible inference which the experiment or other observational data possess with respect to the theory or hypothesis under examination. This means that statistics is concerned with the central problem of any scientific investigation. Further, the extent of agreement between experimental data and the assumptions is among the objective factors that govern the acceptance of solutions proposed for scientific problems. In this determination statistical procedures play a prominent part.

The engineer-statistician will find, I think, that his past idea of the nature of statistics was incomplete, if not wide of the mark. He will begin to agree with Warren Weaver's article on "Statistics" in the January, 1952, issue of *Scientific American*, which states,

> The word usually suggests masses of numerical information, but it also describes that department of mathematics which grapples with the complexity of nature by means of samples.

I am confident he will find (to quote further remarks in Wallis' preface) that "even though sound statistical techniques may not be indispensable in the physical sciences, they are invaluable." Furthermore, by both practice and preaching, he will be a leader in spreading this gospel among his associates.

Finally, I sincerely believe that another reason the need has not been recognized is because many, if not most, of our statisticians have a less than perfect understanding of the exact nature of the important problems in the various fields of engineering. I am inclined to think that we need more statisticians who can out-engineer the engineer in solving engineering problems. That would seem to be one of the best ways of convincing him that the methods of studying pigs can be applied to pig-iron.

As an illustration of success in this direction I might call attention to Miss Besse B. Day's paper, "Application of Statistical Methods to Research and Development in Engineering," reprinted from the *Review of the International Statistical Institute*, 1949, and describing some of the work at the United States Naval Engineering Experiment Station at Annapolis. On summarizing the applications in the TV fuze program, she states:

> It was demonstrated conclusively on the fuze program that statistics was a vital tool in the solution of engineering problems of research, development and production. The head of the tube group went on record with the statement that the statistical methods had probably saved several million dollars on that project alone.

HOW COULD THIS NEED BE MET?

The expected answer is: Require each engineering student to take a course in applied statistics. Before accepting this easy answer, which is perhaps a very good one, let us not forget that engineering curricula are bulging at the seams. Some engineering schools have gone to a five-year course, inspite of the obvious financial burden on the student and the accelerated demand to supply industry with product quickly. For the four-year courses there is a continual search to find ways to streamline curricula by deleting or reducing some of the time-honored subject matter. Anyone proposing a required course in SQC should be ready to present a very strong case for dropping out a semester of calculus, or physics, or English.

Another worthy answer was that given by an educational officer to a quality control director for one of our large companies. The director of quality control visited the campus to lodge a request that the particular institution expand its statistical offering for engineers. The answer, in

effect was this: "It is expected that, in the engineering courses, the student will receive incidental training in the statistics which he needs."

This hopeful position reminded me of a college president who usually included in his fall message to his faculty a plea to use their courses as an opportunity to teach their students to speak and write good English. I am confident that although they recognized the importance of the request, they felt nervous about complying with it very fully. I suspect, however, that the president's request did spur the professors to give more careful attention to their own use of English.

I hope the time will come when statistical principles will have their rightful place with other scientific principles in every engineering classroom and laboratory, but in working to hasten that time, we must keep in mind that most engineering teachers are, themselves, the product of engineering education.

In the 1950 report of the subcommittee on College Courses, of the American Society for Quality Control, (a subcommittee for which Professor John A. Henry of the University of Illinois served as chairman), one conclusion reported was

> Industry is exerting pressure for undergraduate statistics on the engineering colleges. This pressure is honorably exerted by the attitude of recruiting personnel. This can and should be intensified by members of ASQC and their associates.

While I thoroughly approve of the general principle; "If you want this country to be different, write your Congressman," and have encouraged direct action by graduate engineers who say, "This is great stuff, but why didn't we get it in college?" I must admit that I have some mental reservations in view of present conditions.

I am not sure that all of our students reach, as undergraduates, the stage of maturity where they can appreciate a full course in applied statistics. Many of the current crop have difficulty in finding summer or part-time work which gives them the necessary industrial experience as the background for applications. The teacher then must play the role of a missionary who has to teach the innocents what sin is before he can convert them.

Nevertheless, it seems a mistake to send students into engineering work without some slight introduction to the elements of simple inference. This is not the appropriate place to discuss the matter in detail but two solutions might be mentioned. One possibility is to put back into college algebra courses the work on probability which has been crowded out in recent years. The other solution, to be used singly or in combination with the first solution, is to require an abbreviated course at about the junior level organized around the binomial and normal distributions and including a liberal amount of laboratory work with sampling experiments.

For graduate students in engineering and science a formal course in applied statistics should be a welcome requirement. In view of the present trend in scientific papers, it is difficult to see how a program of graduate study can be comfortably pursued without some understanding of statistical principles. Such a course could be opened, also, to qualified seniors.

WHAT YOU CAN DO

However, whether applied statistics be elective or required; taught to graduates or undergraduates; in credit courses, part-time courses, or in-plant courses; I believe that the members of the American Society for Quality Control and others interested in the growth of SQC in engineering education have two important opportunities for service.

First, they can assume part of the responsibility of making sure that the teaching is done by people who are competent both in the field of statistics and in the field of industrial application. In my opinion it may be fully as damaging to have the teaching done by a mathematical statistician with no experience in application, as by an engineer with no knowledge of statistics. If we must choose between these two alternatives, let's choose both and have the two specialists work as a team.

In a paper in the December, 1951, issue of the *Journal of the American Statistical Association*, on "Yates' Correction and the Statistician," Franz Adler has hidden the following pertinent remarks, which bear on the manifest advantages of such cooperative effort:

> The mathematical statistician can —and often does—provide logical soundness. It is the business of the research worker who applied the statistical methods to his field to report which one of alternative methods he used brought results most closely consistent with the results of his experience.
>
> The realities of any field are not of necessity identical or parallel to mathematical assumptions. Only in a mutual exchange of ideas and experiences between the mathematical statistician and the practical research worker can it be found which assumptions, which methods, and which procedures fit which field.

The second opportunity for service is that of contributing teaching materials. When teaching applied statistics, the major portion of my time and energy is used in ferreting out appropriate problems for assignment and discussion. I must acknowledge my own gratitude and the gratitude of my students to those engineers who have supplied me with concise, but complete case studies, together with the necessary data. Some I get by begging, a few come unrequested, a limited number I am able to extract from published papers. I am not alone in needing a greater and more varied supply of standard applications. I should like to have at least one from each of the engineering fields (and most should be such that the students can do the necessary numerical work in less than one hour). Again, I think I speak for the vast majority of teachers of applied statistics. To us it seems almost certain that whenever, through cooperative efforts, better teaching materials become available, the need for education will be met more effectively.

CLOSURE

In closing this presentation, let me restate the three questions at issue,

1. How great is the need for SQC in engineering education?
2. Why has this need been so long ignored?
3. How can this need be met?

I believe there is ample evidence that the need is great. Also, I have little doubt that the need can and will be met when it is more universally recognized. It becomes of utmost importance, therefore, to investigate fully the assignable causes why this need for SQC in engineering education has been so long ignored and to either counteract their effect or entirely eliminate them.

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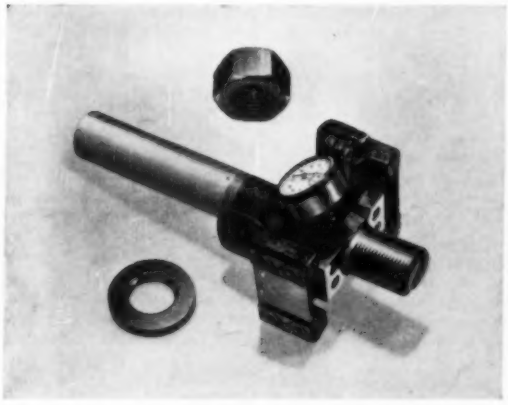

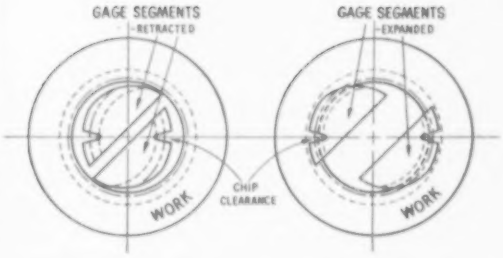

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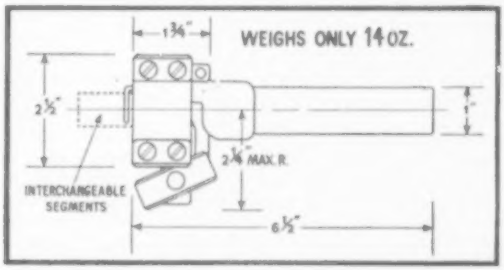

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The Human Factor in Quality Control*

PAUL J. MUNDIE

Humber & Mundie

THE introduction of QC in a plant or a business usually stems from a meeting attended by management people. Frequently the first work centers around demonstrations of distributions and development of charts. After this first flush of enthusiasm takes place, the problems become much more difficult. Problems begin to involve a number of other things. For instance, how does this new QC fit into Inspection? How does it fit into the Engineering and the Production Departments? Is QC an advisory service or is it an operating service? What are we now going to do with this thing that we have developed? It is at this point that I believe we can very well look at the impact that QC makes upon the people who are going to be involved in its use.

What is the impact that QC makes on the people that it touches? In the first place it seems to me that we could stop for a moment and look at the qualities that make a human being what he is. For the purposes of this discussion we can look upon the personality of each man as having three interrelated characteristics.

HUMAN PERSONALITY

The first is that a human personality is made up of intelligence. I do not mean intelligence in the sense that we test it with examination; I mean intelligence as a factor in reality that enables us to predict on the basis of our experience. Intelligence is the functioning ability of the human to grasp or respond to reality. In other words, a person is effective in his intelligence if he can understandingly encompass reality and exercise some control over it. If he can predict, he is intelligent. So the first aspect of human personality is something that is easy for people in SQC to appreciate. It is the ability to comprehend or grasp and respond to reality and to be able to predict.

The second aspect of our personality involves our dealings with the world around us. We feel in response to everything. There is no stimulus which can touch us that does not in some way give us a feeling tone. We feel in response to everything that touches us. We feel in response to things that are said to us. We feel pain, or we feel pleasure. We feel good, or we feel bad. We feel exhilarated, or we feel depressed. We respond with feelings to every single thing that happens around us. Many things are so small that we don't respond very strongly. Our response pattern is usually small in response to a small stimulus. But no matter how small the stimulus, there is a response in feeling. Many of you are in engineering and when you talk about 0.0001 in some quantity or other, you are talking about a small amount. And yet a stimulus as small as that will produce response. The response, it is true, will generally also be on the order of 0.0001, but the important thing is that there will be a feeling response to everything that happens to us.

The third factor that makes up our personality is our fantasy life. This is the way in which things happen as we would like them to occur. The intelligence allows us to see reality, the feelings allow us to have some control, and the fantasy gives us our aspirations and our motivations. Many men feel that the mark of a mature person is that he has no fantasy life. Many people are very proud of being extremely literal. Many engineers have been so trained that they want to be able to touch a thing and to measure it and to feel it. To such people, if it has not quantification, it is not any good. But nevertheless, our whole life experience shows us that there is something in us that gives us aspirations or goals that are beyond quantification and this is the fantasy life. This fantasy life or the imaginative life is the life in which we are in a sense Walter Mitty, great inventor, or Walter Mitty, great explorer. It is true that, if carried too far, fantasy life becomes similar to that of children or mentally disturbed people. It is understandable that a large number of people suspect that fantasy life is not wholesome. There is no doubt that if it is carried too far, we have actual evidence of immaturity. However, even an elementary analysis of our personality will lead all of us to appreciate that our fantasy life, or seeing things as we would like to have them be, becomes a very important aspect of our personality. It is the thing that enables us to take a little criticism, and then go out and either turn it for our own use or say, "Well, I wish I had told him what I really think." It is in fantasy that we become so effective —that is, after the meeting is over.

Now these three factors of intelligence, emotions, and fantasy are critical for an understanding of what I am trying to say.

Our personality includes the three sides of this triangle: The intelligence, or the ability to grasp reality; the feeling of response, or our ability to control ourselves; and the fantasy life which gives us our motivations, our aspirations, and our goals. But none of them can be taken separately. Many people feel that they can be intelligent now, emotional then, and live in fantasy afterwards. The three things cannot be separated. It is futile for anyone to believe that he can go into a group, or work with a group on the basis of pure intelligence. If I try to sell QC, or anything else, to a group on the basis of pure intellectual appreciation, I am almost certain to fail. I must take into account the complex nature of the personalities with which I deal.

QC AS A PROFESSION

Now what does this mean in terms of QC? It means that QC must sit down with itself and decide that sooner or later it is going into industry, business and manufacturing through the back door, through the roundabout way of ekeing its way into inspection and engineering, or it is going to go through the front door and be a profession. I think that all the signs show that SQC or

* Paper presented on the Program of the Sixth Annual Convention of ASQC in Syracuse, New York, May 1952.

QC, taken as a profession, has decided to become a profession and to go through the front door of industry rather than through the back door. It appears to me that the signs of the forthcoming profession in QC are already with us.

You know, in my field, we believe that a profession has certain marks. If it does not have these marks, it probably is not a profession—it is a trade. The marks of a profession that apply to QC today, seem to be these: First, it has a body of organized knowledge that is intellectually communicable. A trade is generally marked by the development of skill by doing the job over and over again. A profession is marked by the intellectual communicability of the subject matter. SQC seems to me to have the first mark of a profession.

The second mark of the profession which it seems to have to date is that a great responsibility is placed upon the individual operator. When a person is operating in the field of SQC, the very nature of the operation makes it difficult for a lot of people to check him and to make certain that his work is right. A great deal of personal responsibility therefore rests upon the practitioner in the field of QC.

In the third place there seems to be an altruism in the profession. All professions must have some altruism in them. However, a true profession deals with work that must be done because mankind had a need that had to be met. Thus the greatness of the older professions, of thelogy, of medicine, of law, reached its highest point when altruism was at its peak.

Since we must all earn a living, I am not going to belabor this point of altruism. We live in a world in which a man must earn his living. But there is, I believe, in all of the people I have met in the field of QC a willingness to go beyond the limits of their ordinary jobs in order to help people understand QC, so I am satisfied that there is this characteristic of altruism.

Now if these characteristics are true, then I think we can assume that QC is likely to go in the front door of business as a ranking profession in its own right. If that is true, then other problems develop. We can say that there are two different sets of problems that come to QC if it is going to become a profession. Both relate to people.

PROBLEMS OF A PROFESSION

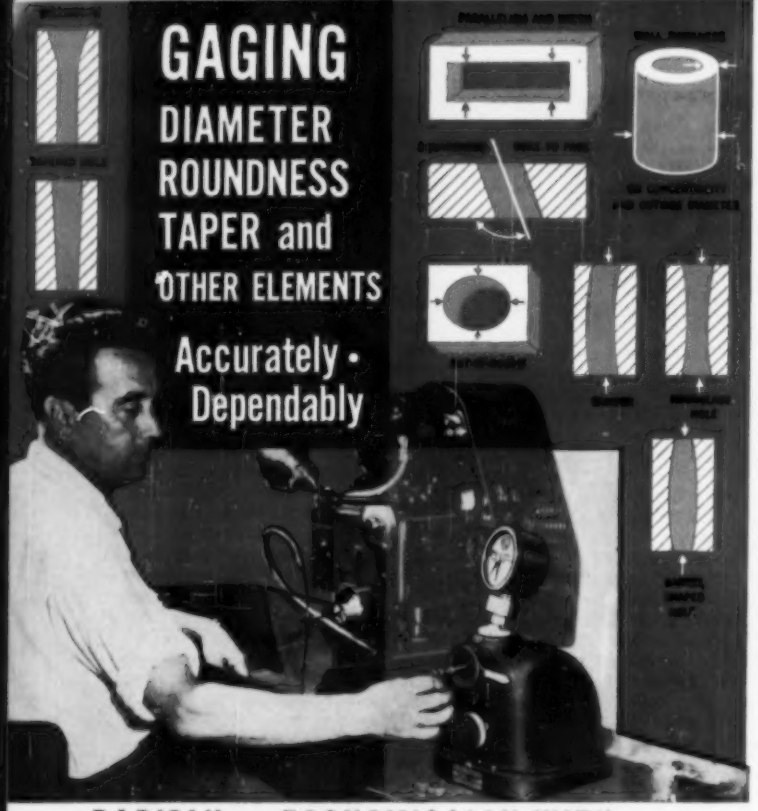
The first group are those of relationships of plant with management, with QC people themselves, and with the production departments of a company. In regard to management, it seems perfectly obvious that techniques have to be developed for adequately selling QC. It is a human factor, a human element, a purely psychological matter; because if what I have said is true, it is absolutely impossible to do a competent selling job of QC or any other branch of knowledge on a basis of pure intellectual activity alone. We will not accept things merely because our minds give assent. I believe there have been times when the effort has been made to try to sell management on an intellectual basis alone.

The second part of this relationship with other people has to do with the problems within the field of QC itself. There is no question that in such a group as this, there will be tremendous problems of personal understanding of each other. It is a new field and therefore it has drawn large groups of people from many different branches of learning and activity. There will be a percentage of engineers. There will be a number of statisticians. There will be a number of people who come from production control. There will be some people who come out of cost accounting. There will be people who come from every branch of human activity that relates to the running of a business. Because these people come from the backgrounds they do, they are going to see things in the light of their experiences. They are, in other words, going to interpret in the light of the things that they have known so that the differences of opinion that would be expressed in a meeting of this kind on any technical issue will probably be very great. A great mathematician and a great statistician will be interested in developing further theory. On the other hand, a man who comes into this field out of production will be so interested in getting some quick utility out of it that he may feel very strongly that the less emphasis placed on the mathematics of the problem, the better. He would like to develop a technique in which theory does not make its appearance at all. In between these two extremes there will be all manner of people who have to learn to get along together.

Is it not obvious with the diverse backgrounds of the people who are in QC that it behooves the members to be exceedingly conscious of the needs and feelings of the rest of the group, so that they do not press their views beyond what is reasonable? I am particularly concerned that the QC people try to develop in themselves a breath of understanding of the needs of the people with whom they deal so that they are conscious of the fact that even with one another they cannot expect agreement and they cannot expect just to give intellectual advice to the group in the shop and in the factories. Many have had excellent results. So far the results seem to be successful in spite of the personality of the QC engineer who is trying to do the job, and in spite of the relationship he has with the superintendent, the manager, or whoever else he is dealing with in the shop. It is a personal matter thus far, and a technique has not yet been developed that is foolproof.

Let me illustrate this with a reference to a great institution in Chicago. Many years ago Hull House was started by Jane Addams. It is still a very great social welfare institution in Chicago, but no one has ever yet been able to reach the stature of Jane Addams. Jane Addams and Hull House were almost synonomous in American life and in particular in Chicago life. Hull House was the product of a great idea of a great woman. Unfortunately, no one has been able to develop a technique that will ensure continuing greatness in a settlement house.

No one has been able to formulate a technique that can be guaranteed to make QC great; but because it does have the characteristics of a profession, it appears to me that there will be the development of the necessary techniques. I don't believe that QC is destined to remain a parallel to Jane Addams and Hull House. I believe that it is more likely to be analogous to the development of medicine. Today we can go to any physician, and while we know that he may have certain shortcomings in one field or another, he at least has a reasonable and fundamental ability to deal with the situation that we bring to him. We believe that an analogy can be drawn from a profession such as medicine rather than that the analogy must always follow that of the great person idea, taking Jane Addams as an example.



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Now, in dealing with people, whether in management or in one's own group or in production, it seems to me essential that we have some further understanding of what causes people to act and think the way they do. I have already discussed what seems to make us up as a personality. How do we act?

HUMAN ACTIONS AND REACTIONS

I think the first thing that is essential for QC people to keep in mind is that there is a constant unwavering and unremitting tendency on every human being's part to project. Projection simply means that man tends to see, to hear, to feel, to taste, and to smell what he needs to feel, to hear, to taste and to smell. We project our own needs out into life. I see you as I need to see you, and you see me as you need to see me. Of course, it is perfectly true that the normal person ties this projection into a reasonable adjustment with reality. But, in general, I see you as I need to see you. I can see you as a pleasant person if I need to see a pleasant person out in front of me, or I can see an unpleasant person. We constantly project; as a matter of fact, it has been discovered that we so project our needs out into the outer world that a whole system of psychology has been developed around the idea that if we can get a person to express his needs through projection of himself, we will get of picture of his personality.

Now, without delving into the psychology of this point, I want to say that the fact that every human being projects must sooner or later be taken into account if this profession is to reach the heights you want it to reach. The president or the vice president of a company must be sold on the basis of *his* needs—not *your* needs. Some will try to sell QC on the basis of their needs because they project their needs. This tendency towards projection of our own needs can only be avoided by developing insight, or self-understanding. Insight into one's self and insight into the other person are the only safeguards I know which are worth anything against this constant tendency we have to project. He who does not have to project hostility tends to be a relaxed person. He is also quite non-defensive. He does not have to argue. When someone says to him, "I think QC is without merit," he doesn't have to say,

"Well, I would like to tell you that it has saved us $400,000 in our plant in the last year." The non-defensive, well adjusted practitioner in the profession of QC would be more likely to say, "You say this field is without merit. That interests me. Would you tell me why you feel that way?" Because he is non-defensive about it, he is relaxed to the point where he does not have to fight it any more.

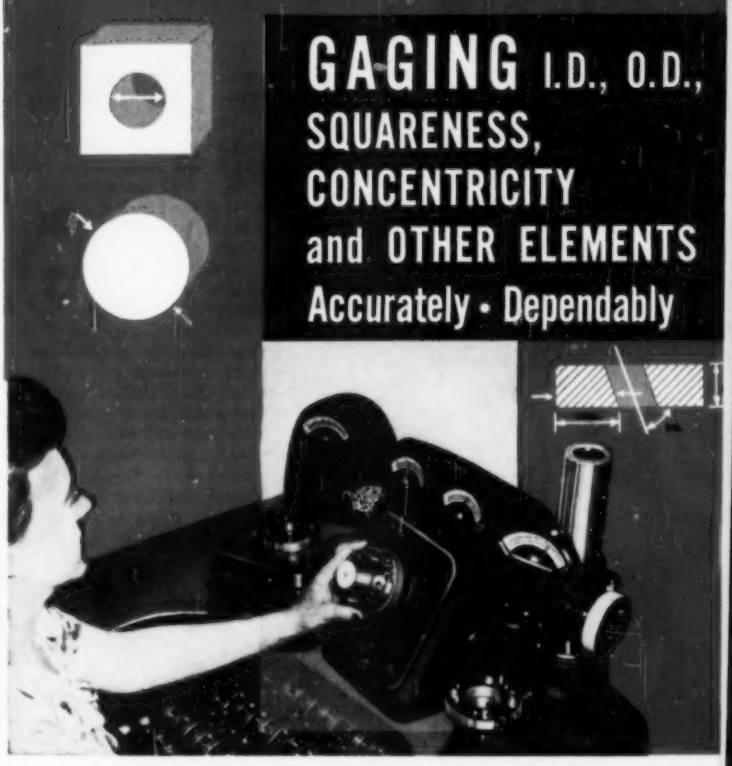
I would like to emphasize that if QC is to be sold on the level of top management or to the worker or anywhere in between, it is essential that we understand the constant tendency we have to project our own feelings, shortcomings, anxieties, fears, in order to get enough insight to be able to go at this in a relaxed way.

Another thing to be kept in mind if we are to sell QC is that in a new field the people involved in it are very easily frustrated, become very touchy on the subject because it seems there is so much to do and so little time in which to do it. Therefore it is only natural that a man can expect, if he is in the field of QC, there will be times when he will begin to doubt himself because he feels frustrated. He must get ready for these feelings.

Furthermore, I think we must appreciate the tendency all of us have to resist change. Change is difficult because we all like to develop habits. The moment we have to change anything, there is a natural tendency to resist the change because it does not seem as if the new thing is worthwhile. It seems to me that it is not remarkable at all that you have an old superintendent in your plant who says, "I doubt the value of this whole thing," or "I think the whole thing is no good." There is nothing at all remarkable about that because it is a perfectly natural tendency to resist change.

OTHERS INTERESTED IN QC

Now that brings up what I consider a very important aspect of this matter: I suspect that since we do project, since we are easily frustrated, since we do resist change, you might just as well get ready to bring more people at least into the fringe of QC. If these things are true about people, we are not ever going to be able to cram a goal of any kind down their throats. A number of industrial psychologists have made studies of productivity of



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workers under various controlled circumstances, where the superintendent fixed the normal output, where a time study fixed the normal output, where a production department fixed the normal output, where the production department fixed the timing of a line, where a psychologist had talks with the people and helped them determine a goal for themselves, and where the workers with their foremen decided upon a goal by themselves. It was found that the only motivation that produced a significant difference over the average of all the rest was the motivation that came when a small group of workers doing the actual work themselves fixed their own goal. As far as the evidence is now available, there seems to be no way in which we can impose a goal upon another person that is in any way significant as far as making him produce faster or better. The only real improvement comes when a man sets, or people set their own goals. There are examples of this in any plant. You have seen the second shift decide to show how much better it was than the first shift. This applies at all levels. The whole process can be taken along only as fast as the people can take it and can set their own goals. Any effort to push them further is going to result in increased frustration on the part of the QC people.

I think a great deal more time should be spent in the formulation of goals before an effort is made to approach those goals. What are the goals and why should they be reached? Whenever they are reached on the executive office floor of a company's office building and then translated a week later down through somebody named Joe into a small press operation, don't think that you are going to get very far.

I know of a foundry that attempts to maintain a control chart in cupola temperatures. It is a gray-iron foundry and at the moment the only person who is interested in it is the manager. The metallurgist and the men have no interest in it and the chart has all the variations you would expect from an uncontrolled operation. Yet, the manager keeps a chart there hoping that one of them will become curious enough to look at it some day and wonder if something couldn't be done about the variations. But as long as there is no goal here which is accepted by the individuals involved in it, it is going to be an uncontrolled operation.

People are not all alike, but so often we insist that we treat them as if they were alike. Many supervisors will not take into consideration the individual differences among people. Of course, we do take these differences into account when we say that John is not competent for a job, but we often deny the same differences in personality. I have heard men say "Business is no place for playing favorites and any variation in your treatment is favoritism." This remark is nonsensical. Each person is different. He is a different complex of feelings and of fantasy. Because he is different he is going to have to be handled differently. In other words, we are going to use one technique to sell this to the president and another technique to sell it to the executive vice president and probably still a third technique to sell it to an engineering department. There may be five or six levels at which this program must be adopted and believed in. There may be five or six methods by which it is possible to have these people understand the subject matter and the scope of QC.

THE SUBSTANCE OF QC AS A PROFESSION

If QC is to be successful, the mathematics of it and the statistics of it are going to be one of the smallest things in it. They are essential, certainly. They are essential in the same way that a knowledge of anatomy is essential for surgery. But if it is going to be a true profession, it is going to be an art rather than a science. When the physician deals with us, he is acting as an artist. The physician is as true an artist as the man who paints a picture. What is he doing? He takes all the sciences that comprise medicine and brings them together in a great *gestalt*.

Similarly, QC is not a science. It is a group of sciences. Its application is an art. The profession of QC is going to be an art and is going to be based upon a number of sciences. It is based upon the science of mathematics and all of the correlative sciences. It is certainly based upon a science of measurement. But when the whole thing is wrapped up, it is going to contain its psychological aspects. It is going to be an art that is based upon a dozen different sciences. The goal that is ahead of a profession that looks at itself in this professional light is a very great goal because of the good that can be accomplished both to the individual and to the companies that make use of it.

I have seen a great many men at one QC meeting or another who see the implications of this instrumentality if it can be put to work. You can see what it would mean to a business; you see that it could be the next great revolution in business; it could be a revolution as great as a punch press or an assembly line or interchangeability. I have seen in many of you the feeling that there is a tremendous force here if it can be properly developed. The system of QC applies even to the work of the president. If he ever sees the point of what this means, he can apply it to his own office. It is not only in the factory, it is also in the office.

Some have seen the possibilities in QC. There is a possible application to the development of every single human being. The concepts that underlie QC are applicable for our own personal use. We can manage our own affairs under a program of QC. There is so much in life that will respond to QC that the path of growth has had only a few steps taken along the route. I feel strongly about this since the field of psychology has certain similarities with your field. We know quite a bit now; but what we know now is almost infinitesimal compared with what we don't know. We have gotten to the point where we can do well in describing the personality of a man. We can tell reasonably well what he is like and yet we still haven't developed very good techniques for making him better. Similarly you have considerable skills. You are very good at putting your finger on the difficulty. You are not quite as good as you would like to be in doing something about fixing the difficulty.

I think that your field will require two parallel developments. One line will be the development of technical knowledge. The other line will be the development of the personal skills and the art skills to make the profession function with effectiveness. I believe that the more time that is given to the development of this personal factor, the more success you are going to have.

Correlation of Conventional and Accelerated Test Conditions for Heater Burnouts by the Logarithmic Normal Distribution

RICHARD D. GUILD

Sylvania Electric Products, Inc., Emporium, Pennsylvania

THE radio tube industry has always been interested in developing a test technique and quality control* tool applicable to vacuum tube manufacture which does not suffer from the disadvantage of having an interval of many hundreds, or even thousands, of hours between the beginning of the test and the acquisition of life information. Sylvania, in conjunction with the Signal Corps Engineering Laboratories,* for the last two years has been devoting time to a project of this nature. A tube type is being investigated for heater burnout failures under this project.

Analysis of the failure pattern for heater burnouts has shown that the frequency distribution of failures with respect to time was markedly skewed to the right and hence could not be considered normally distributed. However, a transformation was made in which the hours of life of each tube was changed from the natural number to a logarithm. By this transformation the normal distribution curve was found to be a satisfactory description of heater burnout data.

* Publication covers only a portion of the work done under Contract W36-039-sc-44520 and does not denote final acceptance of this method for Signal Corps usage.

Heater burnout data under conventional and accelerated conditions analyzed by the logarithmic normal distribution are shown in Tables 1 and 2. Figure 1 shows the calculated cumulative percent failure curve for the accelerated test superimposed on the calculated cumulative percent failure curve for the conventional test. The observed points of cumulative percent failure are also plotted for each of the calculated curves.

Knowing that both conditions produce similar failure patterns, a method of correlation between the failure patterns is desired.

Using the statistics, the arithmetic mean of the logarithms X_{log} and the standard deviation of the logarithms σ_{log} established under both conditions, a method of correlation has been developed. The fundamental reasoning in the development of this correlation method is as follows: Using natural numbers, a ratio may be formed of the values of the hours of life corresponding to the same percent failure on two distributions. If all such ratios equal the same constant, then the ratio of the arithmetic means and of the standard deviations of

TABLE 1—**Conventional Life (Coded Data)**

$\bar{X}_{log} = 2.844$; $\bar{\sigma}_{log} = 0.268$; N = 149 tubes

	Conventional Life					Cumulative Failure Curve				
No. of Hours	Lower Limit	Upper Limit	Log of Limit	X_{log} $(\log X - X_{log})$	X_{log} σ_{log}	% Area Bet. Normal Curve and Limit	% Failure in Class	Cumulative % Failure Calculated	No. of Observed Cumulative Failures	Cumulative % Failure Observed
< 100						50.00	.08	.08	0	0
100 < 200	100		2.03	.844	3.15	49.92	2.04	2.12	4	2.7
200 < 300	200		2.301	.543	2.03	47.88	6.41	8.53	12	8.1
300 < 400	300		2.477	.367	1.37	41.47	9.88	18.41	23	15.4
400 < 500	400		2.602	.242	.90	31.59	11.05	29.46	47	31.5
500 < 600	500		2.699	.145	.54	20.54	10.67	40.13	66	44.3
600 < 800	600		2.778	.066	.25	9.87	18.58	58.71	86	57.7
		800	2.903	.059	.22	8.71				
800 < 1000		1000	3.000	.156	.58	21.90	13.19	71.90	101	67.8
1000 < 1200		1200	3.079	.235	.88	31.06	9.16	81.06	118	79.2
1200 < 1400		1400	3.146	.302	1.13	37.18	6.12	87.18	132	88.6
1400 < 1600		1600	3.204	.360	1.34	40.99	3.81	90.99	137	91.9
1600 < 1800		1800	3.255	.411	1.54	43.82	2.83	93.82	140	94.0
1800 < 2000		2000	3.301	.457	1.71	45.64	1.82	95.64	144	96.6
2000 < 2200		2200	3.342	.498	1.86	46.86	1.22	96.86	145	97.3
2200 < 2400		2400	3.380	.536	2.00	47.73	.87	97.73	145	97.3
2400 < 2600		2600	3.414	.570	2.13	48.34	.61	98.34	146	98.0
2600 < 2800		2800	3.447	.603	2.25	48.78	.44	98.78	148	99.3
2800 < 3000		3000	3.477	.633	2.36	49.09	.31	99.09	148	99.3
3000 <						50.00	.91	100.00	149	100.0

TABLE 2—**Accelerated Life (Coded Data)**

$X_{log} = 1.337$; $\bar{\sigma}_{log} = 0.3284$; N = 30 tubes

No. of Hours	Accelerated Life: Lower Limit	Upper Limit	Log of Limit	X_{log} (log X − X_{log})	X_{log} / $\bar{\sigma}_{log}$	Cumulative Failure Curve: % Area Bet. Normal Curve and Limit	% Failure in Class	Cumulative % Failure Calculated	No. of Observed Cumulative Failures	Cumulative % Failure Observed
< 5						50.00	2.62	2.62	0	0
5 < 10	5		.699	.638	1.94	47.38	12.53	15.15	4	13.3
10 < 15	10		1.0	.337	1.03	34.85	16.06	31.21	9	30.0
15 < 20	15		1.176	.161	.49	18.79	14.41	45.62	13	43.3
20 < 25	20		1.301	.036	.11	4.38				
		25	1.398	.061	.19	7.53	11.91	57.53	17	56.7
		30	1.477	.140	.43	16.64	9.11	66.64	22	73.3
30 < 40		40	1.602	.265	.81	29.10	12.46	79.10	25	83.3
40 < 50		50	1.699	.362	1.10	36.43	7.33	86.43	26	86.7
50 < 60		60	1.778	.441	1.34	40.99	4.56	90.99	27	90.0
60 < 70		70	1.845	.508	1.55	43.94	2.95	93.24	28	93.3
70 < 80		80	1.903	.566	1.72	45.73	1.79	95.73	28	93.3
80 < 90		90	1.954	.617	1.88	46.99	1.26	96.99	28	93.3
90 < 100		100	2.0	.663	2.02	47.83	.84	97.83	28	93.3
100 < 110		110	2.041	.704	2.14	48.38	.55	98.38	29	96.7
110 < 120		120	2.079	.742	2.26	48.81	.43	98.81	29	96.7
120 < 130		130	2.114	.777	2.37	49.11	.30	99.11	29	96.7
130 < 140		140	2.146	.809	2.46	49.31	.20	99.31	29	96.7
140 <						50.00	.69	100.0	30	100.0

the two distributions is equal to the same constant and conversely. This constant ratio between the two distributions also exists between the individual items making up the distributions. In determining an accelerated test this principle would mean that failures under an accelerated condition should fail in a constant percentage of the time required under conventional conditions.

Considering a normally distributed failure pattern under conventional and accelerated conditions, the above criteria could be met in the following manner. After determining the constant formed by the arithmetic mean of the conventional test divided by the arithmetic mean of the accelerated test, multiply the constant by the standard deviation under the accelerated condition. If the resulting calculated standard deviation is not significantly different from the standard deviation under the conventional condition, the above criteria would be fulfilled.

When the pattern of failure follows the logarithmic normal distribution a constant percentage change in the individual items making up the distribution has no effect on the standard deviation of the logarithms. Consequently, if the standard deviations of the logarithms under conventional and accelerated conditions are not significantly different, the above criteria are again fulfilled when the logarithms of the geometric means and dispersions about the logarithms of the geometric means are converted to natural numbers.

A mathematical proof for this method of correlation is presented in the Appendix. From the data mentioned, the method is demonstrated in the following example.

$(\bar{X}_c)_{log} = 2.844$ $\qquad$ $(\bar{X}_a)_{log} = 1.337$

$(\bar{\sigma}_c)_{log} = 0.268$ $\qquad$ $(\bar{\sigma}_a)_{log} = 0.3284$

Change the logarithms of the geometric means and dispersion about the geometric means to natural numbers, then

$$\frac{G_c}{G_a} = \frac{698.3}{21.7} = 32.2$$

$$\frac{\text{antilog}\,[(\bar{X}_c)_{log} + (\bar{\sigma}_c)_{log}]}{\text{antilog}\,[(\bar{X}_a)_{log} + (\bar{\sigma}_a)_{log}]} = \frac{1294.2}{46.3} = 28.0$$

However, by the F test $(\bar{\sigma}_a)_{log}$ is not significantly different from $(\bar{\sigma}_c)_{log}$. Therefore substituting $(\bar{\sigma}_c)_{log}$ for $(\bar{\sigma}_a)_{log}$ in the previous equation

$$\text{antilog}\,[(\bar{X}_a)_{log} + (\bar{\sigma}_c)_{log}] = 40.2$$

$$\frac{\text{antilog}\,[(\bar{X}_c)_{log} + (\bar{\sigma}_c)_{log}]}{\text{antilog}\,[(\bar{X}_a)_{log} + (\bar{\sigma}_c)_{log}]} = \frac{1294.2}{40.2} = 32.2$$

Although the subject of accelerated life involves many statistical and electrical problems which have not been answered, it is felt the above approach in correlating conventional and accelerated tests for burnout failures is sound.

APPENDIX: Derivation of the Equation for an Ideal Accelerated Condition

Let X = Hours of life of a failure under conventional conditions

KX = Hours of life of a failure under ideal* accelerated conditions (where K is a percentage)

n = Sample size

$\overline{X_c}$ = Arithmetical mean of conventional life

$\overline{X_a}$ = Arithmetical mean of accelerated life

Then the sum of hours of life of failure for n tubes under conventional conditions is:

$$\Sigma X = X_1 + X_2 + X_3 + \ldots + X_n$$

The sum of hours of life of failure under ideal accelerated condition is:

$$\Sigma KX = KX_1 + KX_2 + KX_3 + \ldots + KX_n$$

In a similar manner, if

logX = logarithm of hours of life of a failure under conventional conditions

(logK + logX) = logarithm of hours of life of a failure under accelerated conditions, where K is a percentage

$(\overline{X_c})_{log}$ = arithmetical mean of the logarithms under conventional life

$(X_a)_{log}$ = arithmetical mean of the logarithms under accelerated life

G_c = geometric mean of conventional life

G_a = geometric mean of accelerated life

Then

$$\Sigma \log X = \log X_1 + \log X_2 + \log X_3 + \ldots + \log X_n$$

$$\Sigma (\log X + \log K) = (\log K + \log X_1) + (\log K + \log X_2) + \ldots + (\log K + \log X_n)$$

$$(X_c)_{log} = \sum \frac{\log X}{n}$$

$$(X_a)_{log} = \sum \frac{\log X + \log K}{n} = \log K + \sum \frac{\log X}{n} = (X_c)_{log} + \log K$$

$$G_a = KG_c$$

$$\frac{G_c}{G_a} = \frac{1}{K} \qquad (1)$$

$$(\sigma_c^2)_{log} = \sum \frac{(\log X - X_{log})^2}{n}$$

$$(\sigma_a^2)_{log} = \sum \frac{[(\log K + \log X) - (\log K + X_{log})]^2}{n} = \sum \frac{(\log X - X_{log})^2}{n}$$

$$(\sigma_c^2)_{log} = (\sigma_a^2)_{log} \qquad (2)$$

* Under an ideal accelerated condition each tube will fail in a constant percentage of the number of hours required under conventional life. Thus

$$\overline{X_c} = \frac{\Sigma X}{n}$$

$$X_a = \frac{\Sigma KX}{n} = K\frac{\Sigma X}{n} = K\overline{X_c}$$

$$\frac{\overline{X_c}}{X_a} = \frac{1}{K}$$

$$\sigma_c^2 = \sum \frac{(X - \overline{X})^2}{n}$$

$$\sigma_a^2 = \sum \frac{(KX - K\overline{X})^2}{n} = K^2 \sum \frac{(\overline{X} - X)^2}{n}$$

$$\frac{\sigma_c}{\sigma_a} = \frac{1}{K}$$

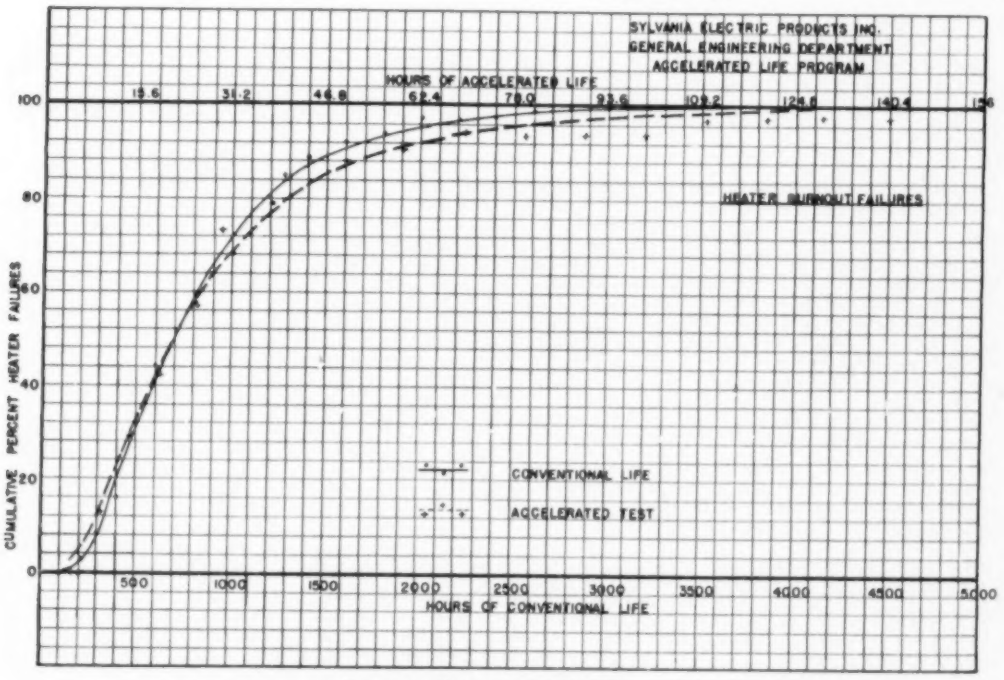

Figure 1—**Heater Burnout Failures**

The height of an ordinate is

$$Y = \frac{1}{\sigma_{\log}\sqrt{2\pi}}\, e^{-L}$$

where

$$L = \frac{[\log X - (X_c)_{\log}]^2}{2\sigma_{\log}^2}$$

and the area ϕ under the curve is

$$\phi = \int_{-\infty}^{\log X} \frac{1}{\sigma_{\log}\sqrt{2\pi}}\, e^{-L}\, d(\log X)$$

At the equivalent percent failure

$$\phi_c = \phi_a$$

$$Y_c = Y_a$$

therefore

$$\frac{1}{(\sigma_c)_{\log}\sqrt{2\pi}}\, e^{-L_c} = \frac{1}{(\sigma_a)_{\log}\sqrt{2\pi}}\, e^{-L_a}$$

where

$$L_c = \frac{[\log X_c - (X_c)_{\log}]^2}{2(\sigma_c)_{\log}^2}$$

$$L_a = \frac{[\log X_a - (X_a)_{\log}]^2}{2(\sigma_a)_{\log}^2}$$

By Eq. 2 when $(\sigma_c)_{\log}$ is not significantly different from $(\sigma_a)_{\log}$

$$(\sigma_a)_{\log} = (\sigma_c)_{\log}$$

$$e^{\log X_c - (X_c)_{\log}} = e^{\log X_a - (X_a)_{\log}}$$

Taking the natural logarithm of both sides

$$\log X_c - (X_c)_{\log} = \log X_a - (X_a)_{\log}$$

$$\frac{X_c}{X_a} = \frac{G_c}{G_a}$$

and since from Eq. 1 $G_c/G_a = 1/K$

$$\frac{X_c}{X_a} = \frac{G_c}{G_a} = \frac{1}{K}$$

If K is changed from a percentage to a constant

$$\frac{X_c}{X_a} = \frac{G_c}{G_a} = K'$$

The Operating Characteristic of the Average Chart

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INTRODUCTION

In the first phase of process control by variables (No Process Standards Given) we wish to determine whether or not a process is in control, basing this decision solely on data in hand from the recent past. A natural question arising at this point is "How much of this past data do we need to insure that the X and R charts give a reliable indication of the actual state of the process?" Although it is frequently recommended that the charts be based on at least 25 samples of 5, no precise information is supplied concerning the relative merits of using this amount of data as opposed to using 20, or 10, or even three or four samples of 5. In what follows we investigate the ability of the X-chart to detect shifts in the process level, in cases where the amount of past data ranges from two samples of five to 25 samples of ten.

STATE OF THE PROCESS

Let us limit our discussion to the following two possibilities for the state of the process:

a. Process In Control

Here we assume that the distribution of the process (i.e., the distribution of individual items of product) is normal with fixed mean μ, and fixed standard deviation σ, both unknown.

b. Mean Out of Control

In this case we again assume that the distribution of the process (at any particular time) is normal with fixed but unknown standard deviation σ, but now the process mean is regarded as a chance quantity itself, having a normal distribution with unknown mean μ and standard deviation $\theta\sigma$, where θ is a positive constant.

Our choice of state *b* is motivated by practical considerations. Since shifts in the mean of an industrial process might occur at any time and be of any magnitude, an assumption which assigned specific values for these shifts would be of limited interest. By treating the process mean as a chance quantity, we are taking into account the "average effect" of many independent assignable causes of varying magnitude. Although we are unable to specify the size of any particular shift, a measure of the magnitude of the fluctuation in a whole series of shifts is provided by the constant θ.

Actually, state *a* is a special case of state *b* when $\theta = 0$. Both states are illustrated in Figure 1, where several possibilities are shown corresponding to various values of θ.

THE OPERATING CHARACTERISTIC

Since either of these states may be present, we are confronted with two types of errors. First, we may get out-of-control points on the chart when the process is actually in control. The chance of this occurring is termed the Type I Error. On the other hand, we may get no out-of-control points when the process level is actually shifting. The chance of this happening is called the Type II Error. To see how large these errors are for various numbers of samples, we focus our attention on the "Operating Characteristic" of the X-chart.

This operating characteristic, or OC curve, gives a graphic picture of the ability of the X-chart to detect trouble. Corresponding to a given amount of fluctuation in the process mean (measured by θ on the horizontal scale) the vertical scale gives the probability P that the chart will show control. OC's are shown in

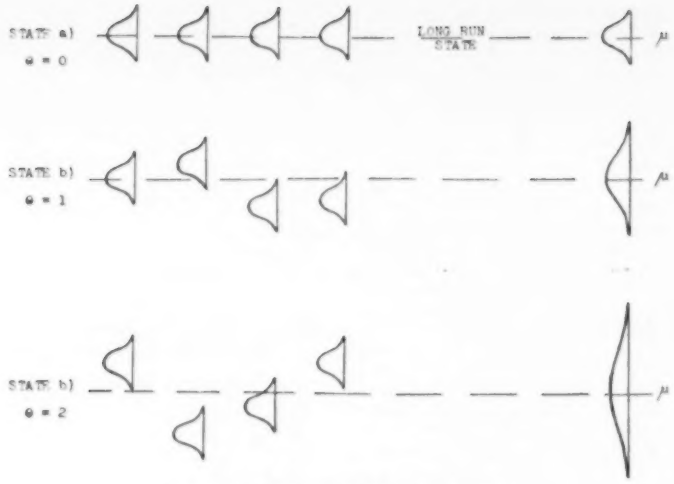

Figure 1—**Possible States of the Process**

Figure 2 for X-charts based on 2, 3, 4, and 25 samples of 5.* When the process is in control (θ = zero), we find the following information by reading the intercepts on the vertical scale in Figure 2:

The chart based on 2 samples of 5 will show control approx. 100% of the time.
The chart based on 3 samples of 5 will show control approx. 99% of the time.
The chart based on 4 samples of 5 will show control approx. 99% of the time.
The chart based on 25 samples of 5 will show control from 94 to 97% of the time.

These figures, together with those in Table 1, indicate the way the Type I Error increases as the amount of data increases. Using two samples of five, the X-chart will, for practical purposes, never have out of control points due to chance alone—while in the case of 25 samples of five, from three to six charts out of every hundred will, on the average, have points out. However, this should *not* lead us to conclude that it is better to use a small number of samples, for we have yet to investigate what happens when the process is out of control. For example, when θ = 1, the Type II Errors are as follows:

The chart based on 2 samples of 5 *fails* to indicate trouble 89% of the time.
The chart based on 3 samples of 5 *fails* to indicate trouble 69% of the time.
The chart based on 4 samples of 5 *fails* to indicate trouble 51% of the time.
The chart based on 25 samples of 5 *fails* to indicate trouble less than 3% of the time.

Thus the small Type I Errors for charts based on 2, 3, and 4 samples of 5 are achieved at the expense of tremendous Type II Errors. Comparisons for other values of θ can easily be made by referring to Figure 2.

*Results for other cases are given in Table 1.

ECONOMIC CONSIDERATIONS

The above comparisons of Type II Errors become meaningful only when we know how important it is that we detect shifts of a given magnitude. The present section outlines a useful criterion for judging this importance. It consists of expressing the percent of total production falling outside specifications as a function of θ.

When the process is in state *b* we note that the process mean is different each time a sample is drawn. At first glance, this seems to imply that we can never make any statement about the percent outside specifications, because we never know where the process mean is. At any particular time this is true, but suppose we take an overall view of the process when "averaged" over all time intervals (see Figure 1). Then we find that "in the long run" the process is normal with mean μ and stadard deviation $\sigma\sqrt{(1+\theta^2)}$. In other words, the aggregate effect of a very large number of shifts in the process level is simply to increase the variability of the product. Finally, if we know the distance from μ to the specification limits (measured in units of σ), we can make "long run" statements about the percent outside specifications simply by calculating areas under the normal curve.

Figure 3 shows the results of such calculations for the particular case

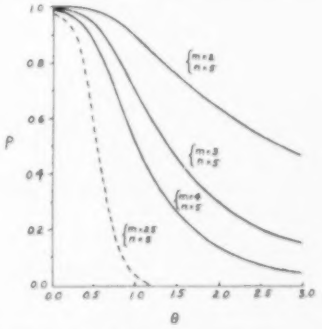

Figure 2—**Operating Characteric of the Control Chart for Sample Means**
m = number of samples;
n = sample size
(The OC for m = 25, n = 5 lies below the dotted curve)

TABLE 1—**Values for the Operating Characteristic Curves**
m = No. of samples; n = sample size
(In most cases only upper and lower bounds are given, since the exact values were not obtained)

θ	m = 5				m = 10				m = 15				m = 20			
	n = 5		n = 10		n = 5		n = 10		n = 5		n = 10		n = 5		n = 10	
0	.99		1.00		.97	.99	.98	.99	.96	.98	.96	.98	.94	.97	.95	.98
1.0					.00	.27	.00	.08	.00	.13	.00	.02	.00	.06	.00	.00
2.0	.00	.14	.00	.05	.00	.01	.00	.00	.00	.00	.00	.00	—	—	—	—
3.0	.00	.04	.00	.01	—	—	—	—	—	—	—	—	—	—	—	—

where the specification limits for individual items of product are located at a distance of $k\sigma$ on either side of μ. For example, when $k = 3$, (i.e. the spec limits are 3-sigma on either side of the "long run" mean μ), we see that the amount of shifting measured by $\theta = 1$ will, on the average, result in about 3½ percent of total production outside specifications. If this is considered serious, a large number of samples is in order. (From Table 1 we see that the chart based on 20 samples of 5 will detect this amount of shifting at least 94 percent of the time, while the chart based on 25 samples of 5 will detect it at least 97 percent of the time.)

The above example illustrates only one of many possible situations. In general (for specification bands of a given width) the more realistic cases where the unknown mean μ is not midway between the limits lead to a much higher percent outside spec's.

SUMMARY

Although the final decision as to how much past data should be used still depends on the nature of the process, it appears that the combination of 25 samples of 5 originally recommended by Shewhart strikes a happy medium in a wide variety of cases. An appreciable reduction in the number of samples used will be accompanied by an appreciable loss in the ability of the $\bar{X}$-chart to detect shifts in the process level.

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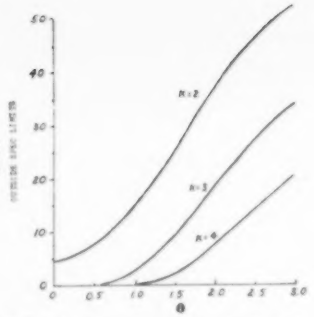

Figure 3—**Percent of Product Outside Specification Limits**

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How to Detect the Type of an Assignable Cause

Part I. Clues for Particular Types of Trouble.

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INTRODUCTION

Before attempting to tell how to detect the type of an assignable cause, engineers would first classify the types of trouble that they encountered and the conditions under which these types of trouble had been found in the past. To take the simplest case, we will assume that we are making some kind of repetitive measurement. With the most rudimentary knowledge of quality control, we would normally continue to make measurements until some individual measurement seemed to be out of line with the rest. Immediately, we would want to know what had gone wrong. Was the measurement real or had we made a gross error or blunder? Causes associated with such occurrences may be taken as the first type that we would like to detect.

A more complex situation is one where, for the first part of a series of measurements, the average is at one value and, later, the average is found to be higher (or lower). In such a case before we had control charts, we often wondered whether or not the shift in the average was worth investigating. However, if the shift in average was "sufficiently large," a concept based on experience, it was almost always possible to find a cause. It was not until the control chart was developed that the engineer had a measure of "sufficiently large," i.e., control limits that made it possible for him to look for trouble with assurance that he might find it. Causes associated with shifts in averages may be taken as the second type that we would like to detect.

Most quality control people will guess that the third type of assignable cause that we might wish to detect is one that is associated with a shift in variability. Such a shift is somewhat difficult to visualize from the tabulated measurements but may be apparent to the trained eye when the values are plotted. Even after graphing, however, it is often hard to decide that one set of data shows a shift in variability associated with an assignable cause and that another does not.

It may logically be argued that all of the important assignable causes produce shifts in either the average or the variability. This is true but there are types of trouble that may not be detected by the customary methods used in detecting such changes. One instance is a gradual change in level, in some cases a trend, which may be taken as indicating the fourth type of assignable cause.

In the foregoing, we have made no provision for detecting cyclical change. It is reasonable, therefore, that we should include causes that are associated with regular but frequent changes in level as the fifth type that we would like to detect.

To the extent that we as engineers have been able to associate physical data with assignable causes, these causes may be classified by the types of physical data that they produce, namely:

1. Gross error or blunder (shift in the individual)
2. Shift in average or level
3. Shift in spread or variability
4. Gradual change in average or level (trend)
5. A regular pattern of change in level (cycle)

If we as engineers had never been able to find causes that produced these types of effects, we would have no need for procedures for detecting them. It is part of our experience as engineers that we consider carefully the pedigree of each set of data that we obtain. We want to know what are the likely sources of trouble and what are the probable effects that each type of trouble

would produce. This helps us to decide what type of trouble to look for and what type of statistical test to use to detect it. Before going farther, perhaps we should consider more carefully what we mean by a set of data.

SOME IMPORTANT CHARACTERISTICS OF ORIGINAL DATA

Chemists, physicists, and engineers are always measuring something. Usually, their measurements are recorded in notebooks for future study, analysis, report and, in many cases, prediction. The simplest way to find out about this process is to see what is recorded, why it is recorded, and what is done with the data that are recorded.

If we were to look in one of these notebooks, we would find among the first things recorded the name or initials of the person who made the measurements. Engineers, and scientists generally, have come to recognize differences between individuals. One is considered to be a careful experimenter or observer; another may make careful preparation for an experiment but may not take full advantage of his careful preparation because he fails to record all of the pertinent data. Some observers are partial to recordings ending in five; others to even rather than odd endings. Characteristics of this type are identified with particular individuals and often temper the conclusions that are drawn from a set of observations.

The next most important thing usually recorded is the set of conditions that apply for the test that has been conducted. These conditions are then related to standard procedures indicating in detail the constants used. If, however, the conditions are nonstandard, the modifications are clearly defined, often by both drawing and description. The bugaboo of measurement is how to hold conditions constant for a set of measurements. For this reason, the scientist often records many items that he hopes have nothing to do with his experiment. Among these are such things as the atmospheric conditions including temperature, humidity, barometric pressure, and the like. Since a series of measurements takes time, it means that he must check and record things of this type at various points during the course of the experiment. It is also important that these observations on possible changes in conditions be tied in with the observations themselves, particularly when they may be used to explain variations that are indicative of assignable causes being present. It is because he knows that conditions are likely to change that he is always on the watch for the one or ones that may be responsible for the unexplained part of his observations.

In making these recordings, a good observer pays attention to the time factor. He records the date and very often the time at which each observation is made. He also records his observations in the order in which they are taken. This is because he knows that sometimes he is able to associate or sense some type of variable occurrence, whether recorded or not, that may help to explain deviations in his data which he believes to be the product of some assignable cause.

Finally, the observer records the numbers that provide a quantitative measure. Sometimes the statistician assumes that all of the information is contained in these numbers. However when we consider the problem as we have here, we see that they are simply one of the elements which are to be fitted together into a pattern that will be useful for predicting the results of measurements yet to come. In fact, it is often helpful to consider each measurement, x as an unspecified function of the observer, H, the conditions, C, and the time, t, for example:

$$x_i = f(H_i, C_i, t_i)$$

where the subscript, $_i$, is used to indicate the order in which the measurements were obtained.

The observer and the conditions of test seem to be fairly obvious items to include because of their possible effect on the measurements. The fact that they may change from observation to observation is not so obvious. Recording the time and order of each observation might not occur to the pure mathematical statistician because he often assumes that he is dealing with a random sample. The engineer or scientist is not likely to make this assumption. In the past, he has found that he is more likely to obtain observations that show evidence of the presence of an unsuspected assignable cause than not. On the basis of his experience, it is often helpful to classify such unsuspected assignable causes as indicated above.

OTHER INFORMATION

Up to this point, we have considered only what the engineer or scientist records while obtaining his measurements. We have not asked the question, "How is it that he happened to set up his experiment the way he did?" The answer to this question will often throw light on what should be done in the analysis. In particular, it may suggest what we should look for. The assumptions associated with a given experiment often are:

1. Some previous experiments suggested that a certain procedure would produce the desired result.
2. Difficulties encountered in the earlier experiments suggest the kind of unsuspected assignable cause that may occur in this experiment.
3. In some respects, the results of this experiment are predictable from the results of the earlier experiments.

The characteristics of data, discussed in the previous section, were all of a quantitative nature. In contrast, the information considered here is largely qualitative. However, the statistician must take these things into account if he is to be of maximum assistance in the design and analysis of experiments.

A fourth consideration concerning a new experiment is that it will provide results which will serve to

Editor's Note

This two-part article was prepared for the Third Midwest Quality Control Conference held in Chicago on November 4 and 5, 1948. It covers in more detail material originally presented at the March 17, 1948, joint meeting of the Statistical Techniques Section of the New York Chapter of the American Statistical Association and the Metropolitan Section of ASQC. Subsequently, it has been presented before quality control or statistical groups at Princeton and Cleveland in 1948, New Brunswick and Princeton in 1949, Los Angeles, Albuquerque, and Minneapolis in 1950, and Blacksburg, Va., in 1951.

The fact that it deals with the philosophy of quality control procedures rather than an application has been the major reason for delay in publication. Arrangements have now been made to follow this article with several short ones dealing with applications of the general ideas. In addition, some of these will give more complete information about the specific tests that are mentioned but are not well known by quality control people.

predict the results of yet another future experiment. This future experiment may be a repetition of the present one or another type of experiment that is suggested by the results of the present one and other pertinent information.

There is still another angle that must be considered. This is the matter of how important it is that we make the right decision concerning the presence or absence of an assignable cause. This decision is usually reducible to dollars and cents in one form or another. In the manufacture of a product, we have to consider the possibility of tying up production; in research and development, the possibility of losing time trying to find causes that do not exist. This means that, depending on the particular application, it is desirable to choose analytical procedures and critical limits which if exceeded will either

1. Practically always be associated with an important findable cause, or
2. Simply be usually associated with a findable cause.

Limits that are designed to satisfy the first of these should not be exceeded except on rare occasions when the cause system is, in fact, constant or is subject to minor variations that will have little if any effect on the expected frequency distribution. This is the usual case in manufacture and inspection. Limits are desired that will assist in identifying assignable causes; that is, causes that will produce major changes in quality, before their effect becomes sufficiently important to make it necessary to stop production.

In the second case, we desire to find and identify any cause that is contributing to overall variability. This type of procedure is often desired in research and development work, including production research, where the possible causes may be less well known. We want to find out what is likely to cause trouble so that we may design a procedure or process that will have minimum variability for a given cost or that will be free from any major cause of variability. If the results of one experiment are to be useful in the prediction of the results of another, it is essential that the conclusions drawn from the first be essentially free from any effect that would change in any important way the prediction to be made for the second. Time may be of less value in research work than assurance that all important sources of variability have been investigated and their causes found.

Keeping in mind this background of engineering experience, let us consider and classify the techniques that the mathematical statisticians have devised so that we may determine the value of these techniques in assisting us to locate and identify assignable causes that are important to us. Suppose we start with the problem of identifying a gross error or blunder.

GROSS ERROR OR BLUNDER

Engineers often find a single value that differs markedly from the other values in a set of observations. What to do about such a value has been the subject of many dissertations in the past. Many have attempted to define conditions for rejecting such an observation. In quality control work, our approach to this problem is somewhat different. First of all, we have in mind that such an observation must have a cause. Therefore, we wish to tie the cause and the observation together. We know by experience that we can usually find causes for averages of samples of four that are outside our $\pm$ 3σ limit lines for averages. We also know by experience that we can usually find causes for ranges of samples of four that are above the + 3σ limit for ranges. If the individual value is extremely far from the general run of values, then either the associated average or range or both will be outside the control limits. Even moderately large errors may be identified in this way. But the smaller the gross error, the harder it is to detect. What is needed, therefore, is a test that is specifically designed to catch an observation that is associated with such a cause. The fact that the control charts for averages and ranges catch some cases is of interest but, as we shall see later, the primary reason for using these charts is to detect important changes in level or variability.

The one or two observations in a set that may be attributed to a gross error are characterized by having values that are outside the normal limits of variation associated with individual measurements from a constant cause system. This suggests that a control chart for individual values might be more effective in locating observations affected by gross errors. This is often true. However, a more direct measure is the $p\lambda$ test. Specifically, $p\lambda$ is the probability that the difference between the largest and the next largest value (or between the smallest and the next smallest) in a sample is equal to or greater than some multiple of the standard deviation of the assumed constant cause system. In a practical case, we may not know what multiple of standard deviation to use but must obtain an estimate of it from the data. However, experience has shown that the value calculated from the average range of samples of four is often a good aproximation for this purpose. For this reason, it is often better to obtain the control chart for ranges before applying the $p\lambda$ test. A test may also be made for the difference between the second largest and the third largest (or between the second smallest and the third smallest).

Similarly, the P(g) test provides a measure for an extreme variance. It is based on the ratio of the largest variance in a set of k variances of sample size n to the sum of all k variances. Obviously, it would be nice to have a similar test based on ranges. This is suggested as a good problem for the mathematical statistician.

Thus, we have several procedures that may be used to detect gross errors or blunders. Since each detects such causes in a different way, only the largest errors are likely to be caught by all. Only two tests, $p\lambda$ and P(g) are capable of indicating in a reliable way that the error is of this type.

SHIFT IN AVERAGE

Having identified his blunders, the engineer next looks for important changes in level. Here, the control chart for averages is a logical first choice based on experience. It is a particularly good choice because at the start he wishes to see whether there is any evidence for large changes that are usually easy to find. A second choice is the run chart for runs above and below, first the median and then any value. This may be tried either for averages or for individual values.

Both the control chart and the run chart identify groups of individual values that appear to have been produced under conditions that

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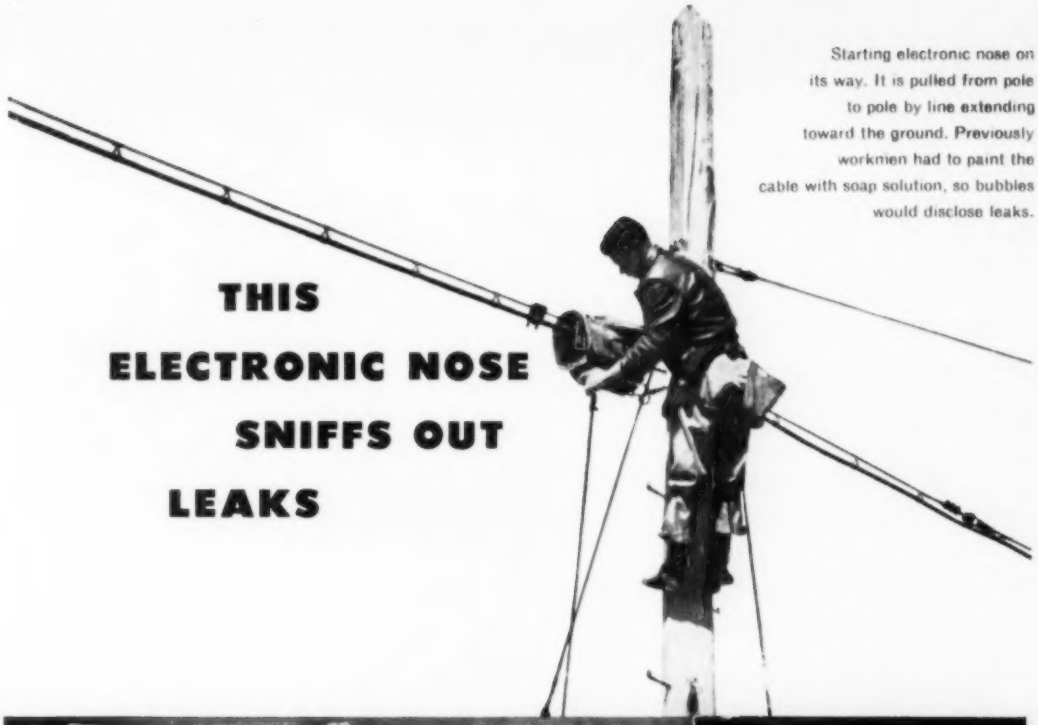

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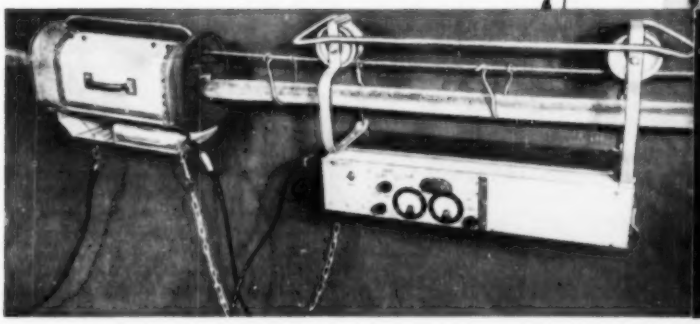

For test, the cable is cleared of protective nitrogen or air, and filled with Freon gas. Case at left collects escaping gas which operates Freon-sensitive detector underneath. At points where Freon escapes through sheath cracks, the box at right—a combined control unit and power supply—rings a bell. Workmen mark the point of leak for later repair.

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differ from other groups. Hence, any deviation may be checked against the conditions that existed when the individual measurements were taken. If a connection exists between the conditions and measured values, it suggests that the conditions should be limited more closely if better control is to be attained in a future set of measurements of the same type. Analysis of variance is suggested as one way of measuring the relative effect of the shift.

SHIFT IN VARIABILITY

Mention has already been made of the use of the range to detect a shift in variability caused by a gross error. It is a good first choice in any case. Engineering experience shows that, ordinarily, change in variability is less likely to occur in a single set of data obtained at one time than in a set of which part is obtained at one time and part at another. What this means is that it is often easier to hold conditions "the same" in the first case than it is in the second. Some of the kinds of causes that the engineer might suspect as being responsible for a shift in variability are changes in observers, conditions of the test, or timing of the measurements. Since most engineers are on the lookout for factors of this type, change in variability is readily identified most of the time.

A second means for detecting change in variability is by control charts for standard deviations of samples of four. Some mathematical statisticians erroneously prefer the use of standard deviations over ranges because it is more "efficient." However, they are not thinking of its efficiency in catching trouble, but instead are thinking of its sampling variation when trouble is not present. When trouble is present, the average range is less affected than the average standard deviation. Under some conditions, the median range provides a better basis for detecting shift in variability than either the average range or average standard deviation. It requires its own set of control constants which differ from those for the average range.

Run charts for ranges are also useful to assist in making diagnoses about change in variability. In case it is desired to measure the magnitude of the shift, recourse may be made to the analysis of variance.

GRADUAL CHANGE IN AVERAGE (TREND)

The three types of causes just considered are all simple in their origin. The fourth type is somewhat more complex. What we would like to identify is a gradual change in average such as might occur in a trend. In some cases, this might be detected by a control chart for averages. If it were known that the probable type of trend was a linear one and that it would extend through the entire set, the simplest test would be a t test of the average of the first half of the set against the average of the second half. Unfortunately, we are seldom at liberty to make this assumption. Only occasionally does a trend continue on through an entire set of observations. Nor is it reasonable to expect that it should. At best, it can be expected to affect only part of a set. This may be at an end or at some place in between.

In view of this, the second choice of test for a trend is the run chart for averages. A third choice is the run chart for individual values. In other words, positive evidence for a trend will be given by a run chart where there is a very long run on one side of the median or two moderately long runs, one on each side of any selected dividing line. Occasionally, analysis of variance and runs up and down are also useful for detecting this type of cause. However, runs up and down of sufficient length to indicate trouble are seldom observed in engineering data except when averages are used.

CYCLICAL CHANGE

The fifth type of assignable cause which is important to the engineer is illustrated best by cyclical variation. This is difficult to detect for several reasons, of which the most important is the effort required to show that a cycle exists. The cycle may be of long or short period. If the period is long and we have sufficient observations to clearly define each cycle, the techniques that apply in detecting changes in averages or trends may be used as a first step. But if the period is short or we have few measurements in each cycle, this will not do at all. Here, the eta chart may be used to advantage. Eta is the ratio of the mean of the squares of the differences between consecutive observations to the variance of a sample. The significance of the use of eta is considered later.

If we are interested in finding the period of the cycle, one technique is the correlogram based on the determination of many lag correlations. This is a complicated procedure that we would like to avoid if possible. How then should we proceed to test for the presence of a cycle?

From the above, it seems reasonable that we should first look for the presence of cycles of long periods because this makes use of the simple techniques that are useful in detecting changes in level. The procedure here would be the same as that for a trend. For shorter period cycles, the control chart for ranges may be useful. The second test of importance for cycles is the eta chart taken in conjunction with the run chart for eta. This serves as a guide as to whether the standard deviation computed from consecutive observations is large or small relative to the standard deviation computed in the usual way. If it is large for most of the samples of four, it is reasonable to assume that a cycle with a short period exists in the data. If it is small, the reasonable assumption is that we have a cycle with a long period.

To supplement these tests, we may try the lag quadrant sum or the lag product-moment correlation. Of these, the lag quadrant sum is the simpler to compute and may serve the purpose in many cases. It has the added advantage that the levels corresponding to given values of probability are almost constant for all sample sizes. The lag correlation may have advantages in some instances. Examination for runs up and down in individual values is sometimes useful but engineering data do not often contain variation detectable by this means. In almost thirty years experience, I have only encountered two cases.

OTHER CLUES TO ASSIGNABLE CAUSES

The five types of clues just discussed appear basic. There are, however, many special situations where other clues are more useful. It is possible that, when these situations are considered by a committee*

* At a Princeton session of the Metropolitan Section, Dec. 8, 1951, the question of forming an ASQC Committee for this purpose was discussed by a panel that included
Thomas A. Budne—Metropolitan Section
William F. Connors, Jr.—Washington Section
Atchison J. Duncan—Baltimore Section
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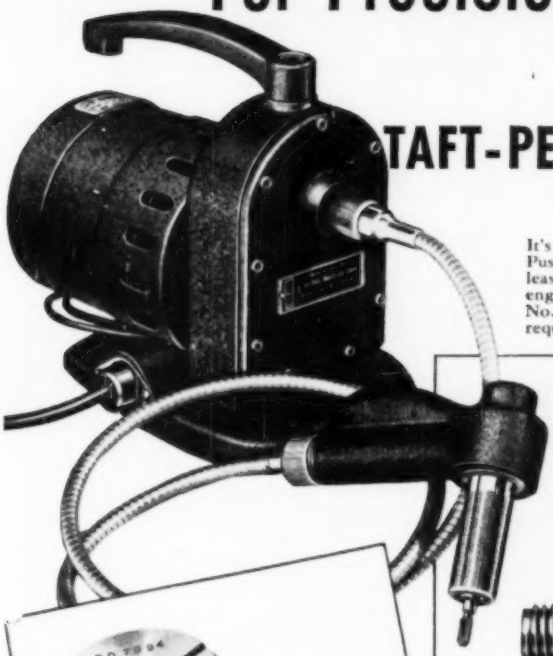

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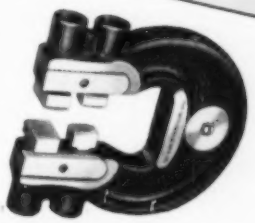

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representing the various fields of quality control work, several other clues will be recommended for consideration.

Suppose, for example, we have a situation where attention should be directed only to high and low values. Casual inspection might suggest that it is typical of rapid cyclical change. A more careful look, when the individual values are plotted in order of observation, shows bunching and gaps in high and low values.* What is needed for this situation is a measure that will take such bunching into account. Where all of the high (or low) values are in a limited portion of the set of measurements, a test has been developed for the occurrence of the r largest (or r smallest) in a series of m consecutive determinations in a sample of n measurements. Runs may also be used to measure bunching. However, a new basis for counting the length of a run may be more appropriate.

One basis that has been suggested as a second test depends on changing the definition of a median to include the set of values that divide the remaining part of the original sample in half. For instance, consider a sample of 4n measurements where no two have the same value. Such a sample may be reduced to size 2n by considering only the values in the highest and lowest quartiles. All other values would then be at the median. If a decision to use such a reduced sample had been made before the sample was taken, measures available for runs above and below the median for a sample of 2n have their usual significance. It is a problem for the mathematical statistician to determine the probability associated with the process when the decision to redefine the median is made after seeing the data. Experience with other tests suggests that this may not have an important effect in changing the criteria from those for the 4n sample.

SUMMARY OF PART I

Part I outlines the problem of the engineer who is making repetitive measurements and who would like to have help from the statistician to assist him in deciding when he should look for trouble. It is assumed that the engineer knows the general characteristics of the cause for which he is looking and wishes to detect. Taking into account the known characteristics of data and the information that the engineer brings to the problem, a selection is made of the statistical tests that seem suitable.

* I have usually considered such occurrence simply as a modification of cyclical change. Dr. Eugene W. Pike, Ratheon Manufacturing Co., prefers to identify it as a sixth basic type which he names, "Erratic Change." His reason for this is that it occurs so frequently in his work.

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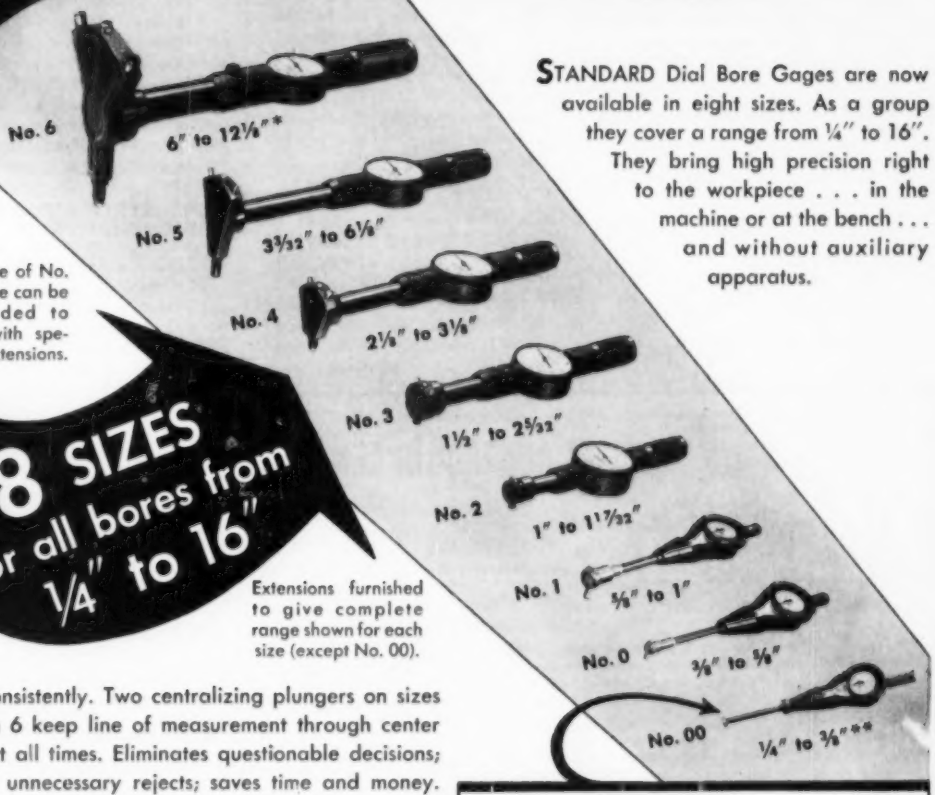

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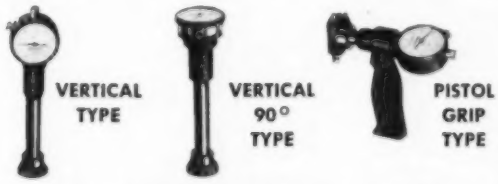

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APPLICATION—CHEMICAL INDUSTRY

STATISTICAL METHODS IN THE CHEMICAL INDUSTRY, O. L. Davies
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Basic concepts and their application to the interpretation of data.

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Practical application of statistical methods in production. (control charts)

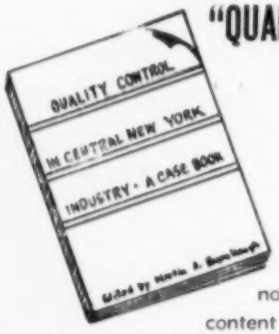
APPLICATION—ELECTRICAL INDUSTRY

ELECTRICITY SUPPLY—A STATISTICAL APPROACH TO SOME PARTICULAR PROBLEMS, R. B. Rowson, South Wales Electricity Board
(The Proceedings of The Institution of Electrical Engineers—Part II, v. 99, n. 68, Apr. 1952, p. 151)

This article discusses the application of various statistical techniques to electrical distribution supply. The fundamental theories of the frequency distribution sampling, etc., are discussed. Problems with respect to plant reliability, transmission and distribution, lightning, voltage fluctuations, radio interference, customer sampling, and others, are discussed.

APPLICATION—MEDICAL & DRUG INDUSTRY

SAMPLING FOR THE DRUG INDUSTRY, R. H. Noel, M.S., Director of Product Coordination, Bristol Laboratories, Inc.
(Drug and Allied Industries, v. 38, n. 5, May 1952, p. 15)



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This is the third in the series of articles discussing the details of the application of SQC to the drug industry. (See the July 1952 bibliography for the first and second articles in this series). The application and basic statistics of sampling, including sequential sampling, are discussed. Tables for the development of sampling plans are given.

SPECIFICATIONS, TOLERANCES AND STATISTICS FOR THE DRUG INDUSTRY, R. H. Noel, M.S., Director of Product Coordination, Bristol Laboratories, Inc.
(Drug and Allied Industries, v. 38, n. 7, July 1952, p. 21)

The setting and interpretation of tolerances is particularly important in the drug industry. Therefore the statistical evaluation of process variation and comparison to specification is very valuable. This article discusses in some detail the statistical implication of tolerances and distribution. Examples cited include the potency of penicillin and the fill of a viscous injectable suspension. (Fourth article in the series)

APPLICATION—MISCELLANEOUS

BETTER PRODUCTION PLANNING FROM CONTROLLED SALES FORECASTS, Frances B. Newman, Tube Department, Electronics Division, General Electric Company, Schenectady, New York.
(Factory Management and Maintenance, v. 110, n. 6, June 1952, p. 108)

Simple control limits are used to establish limits of variation of sales forecasts. This information can eliminate waste in time and money and also assure adequate provision of materials for customers.

APPLICATION OF STATISTICAL METHODS IN THE CASTING PLANT, R. T. Trelfa.
(Tappi, v. 35, n. 6, June 1952, p. 254)

Control charts for visual defects can be used for the control of many important properties of coated paper. An unusual go—no go chart is used, as is a demerit system.

FORMULA FOR QUALITY,
(Modern Packaging, v. 25, n. 2, Oct. 1951, p. 65)

New WILEY Publications in Statistics

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50—100 BINOMIAL TABLES

By HARRY G. ROMIG, *Quality Manager, Hughes Aircraft Company*

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The book also provides a brief summary of the information needed to use the tables for many purposes in the field of quality control. To increase their usefulness, other relations are given for which no probability values may be obtained from the tables and a brief discussion of interpolation is included.

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Statistical Quality Control can be applied with good results to packaging operations. Sampling and control charts can be used. Examples of applications are given.

PRODUCTION OF SPRINGS BY STATISTICAL QUALITY CONTROL, Edward E. Franks, Jr., Torrington Manufacturing Co., Torrington, Connecticut. (Wire and Wire Products, v. 27, n. 2, Feb. 1952, p. 156)

A general discussion of the control of springs with emphasis on a particular test balance for this purpose.

ENGINEERING AND EXPERIMENTS

THE USE OF STATISTICAL METHODS IN RESEARCH, P. M. Schaffrath (Tappi, v. 35, n. 6, June 1952, p. 247)

A brief nontechnical discussion of some of the statistical methods available to the researcher in the pulp and paper industry.

MANAGEMENT AND PERSONNEL

QUALITY CONTROL MANDATORY ON NEW AIR FORCE ORDERS, Dorian Shainin (The Iron Age, v. 169, n. 19, May 8, 1952, p. 119)

The Air Force Quality Control Specification MIL-Q-5923A is discussed. This specification outlines the quality control system required by most Air Force contracts. The details of the system are developed by the contractor and the local Air Force Representative to the mutual satisfaction of all concerned. (Additional information on the Air Force Quality Control system is in a "Special Report—Air Materiel Command" issue of *Aviation Week*, v. 57, n. 5, Aug. 4, 1952, p. 213, "Air Force's Watchdog of Quality.")

WORK SAMPLING (Factory Management and Maintenance, v. 110, n. 7, July 1952, p. 83)

A "Ratio Delay" technique in which statistical methods are applied to production cycles is described in detail. The probability aspect of a frequency distribution is illustrated by dice. A large tally sheet for individual

experiments is included.

Ratio delay is used to collect "What goes on" facts by observation of routine activity. These facts may relate to problems in:

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Material Flow

Details of preparing for, and collecting, these studies, as well as the statistics required, are given.

STATISTICS CAN PUT MORE MEANING INTO YOUR COST ESTIMATES, Paul Frencz, Canadian Industries Limited, Montreal
(Chemical Engineering, v. 59, n. 4, Apr. 1952, p. 143)

Cost estimates usually prepared do not necessarily consider the probabilities that actual results will lie within certain limits about the expected average. A measure of the reliability of a cost estimate is needed. Construction and operating costs, sales volumes and other items are involved.

The standard deviation and correlation are basic statistical methods that can be used for this problem. Several examples of case studies are made from which reliability and significance of results are determined. The problem of improving estimates is also considered.

MISCELLANEOUS

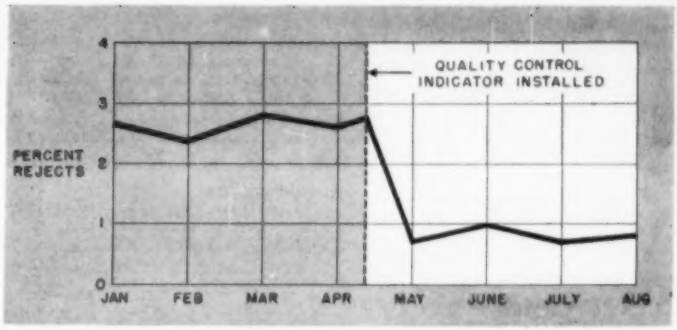
AIRCRAFT QUALITY CONTROL, Phil I. Harr, Director of Quality, Fairchild Aircraft Division
(Aero Digest, v. 64, n. 6, June 1952, p. 86)

This article discusses various industrial activities important to the control of Aircraft Quality. Not particularly SQC.

QUALITY REPORTING

PRINTING RESULTS MEASURED BY STATISTICAL QUALITY CONTROL, Donald Macauley
(American Printer, v. 133, n. 8, Aug. 1952, p. 48)

A system of defect classification is used as the basis of quality control during printing operations. A demerit chart is used to maintain control and record quality variations.



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GENERAL ELECTRIC

SAMPLING PLANS AND RELATED TOPICS

BETTER QUALITY, LESS INSPECTION WITH SEQUENTIAL SAMPLING PLANS, Norbert L. Enrick, P.O.M. Co., New York, N. Y.
(Machinery, v. 58, n. 9, May 1952, p. 168)

Mr. Enrick discusses the advantages and economies of sequentiated sampling. A simple master sampling table for various quality levels is given.

THEORY AND APPLICATION—GENERAL

QUALITY CONTROL METHODS, Dorian Shainin, Hamilton Standard Division, United Aircraft Corporation
(PART I. "What Is SQC?" *Machine Design*, v. 24, n. 7, July 1952, p. 102)
(PART II. "Production Under Control," *Machine Design*, v. 24, n. 8, Aug. 1952, p. 171)

These are the first in a series of articles that will describe the basic theories and techniques of statistical quality control. The utilization of statistical quality control, particularly with respect to tolerances and design, are presented in a simple form.

Natural assembly tolerances, machine performance and related topics are stressed. The control of production in terms of machine capacity is discussed. Under controlled conditions the designer of machine equipment can better predict and understand the variations produced and so incorporate in his designs essential elements needed to produce the products designed.

STATISTICS

A SYMPTOTIC THEORY OF CERTAIN "GOODNESS OF FIT" CRITERIA BASED ON STOCHASTIC PROCESSES, T. W. Anderson and D. A. Darling
(Annals of Mathematical Statistics, v. 23, June 1952, p. 193)

OPTIMUM ALLOCATION IN LINEAR REGRESSION THEORY, G. Elfving
(Annals of Mathematical Statistics, v. 23, June 1952, p. 255)

PROPERTIES OF CERTAIN STATISTICS INVOLVING THE CLOSEST PAIR IN A SAMPLE OF THREE OBSERVATIONS, Julius Lieblein
(Journal of Research of the National Bureau of Standards, v. 48, n. 3, March 1952, p. 255)

GENERAL TECHNIQUE FOR ANALYSIS OF EXPERIMENTS WITH INCORRECTLY TREATED PLOTS, P. M. Grundy
(Royal Statistical Society Journal, v. 13, n. 2, 1951, p. 272)

ESTIMATION OF STANDARD ERROR FROM SUCCESSIVE FINITE DIFFERENCES, P. G. Guest
(Royal Statistical Society Journal, v. 13, n. 2, 1951, p. 233)

VARIANCE OF LEAST-SQUARE ESTIMATES UNDER LINEAR RESTRAINTS, S. Rosenbaum
(Royal Statistical Society Journal, v. 13, n. 2, 1951, p. 250)

TEACHING OF STATISTICS IN SCHOOLS

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(Royal Statistical Society Journal, v. 115, Pt. I, 1952, p. 126)

REPORTED—NOT REVIEWED

SCRAP DOWN, QUALITY UP, THROUGH STATISTICAL CONTROL SYSTEMS, Harold H. Johnson, Metallurgist, Sharon Works, National Malleable & Steel Castings Co.
(Steel, v. 128, n. 21, May 21, 1951, p. 76)
Application of SQC in a steel castings plant.

STATISTICAL TECHNIQUES IN THE MAINTENANCE OF TESTING INSTRUMENTS, W. E. Potte
(Tappi, v. 34, n. 11, Nov. 1951, p. 511)

SHORT COURSE ANNOUNCEMENTS

University of Illinois

The sixth short course in Quality Control by Statistical Methods will be given at the University of Illinois in Urbana, Jan. 20-30, 1953. This course is jointly sponsored by the College of Engineering, the Division of University Extension and the Central Illinois Section of ASQC. Charts for measurements and attribute, sampling, frequency distributions and applications to tolerances will be covered in lectures, demonstrations and problem sessions. For details concerning the course write to Prof. John A. Henry, Dept. of Mechanical Engineering, University of Illinois, Urbana, Illinois.

University of Nebraska

The third annual short course in basic statistical quality control at the University of Nebraska will be offered December 1-5. The instructors will be Professor Niles H. Barnard, and Messrs. Robert Ratner and Irvin L. Reis. There will also be guest speakers from industrial firms.

The fee for the course is $50.00, including text and materials. Registration is open to anyone interested in learning the basic techniques of statistical quality control. Those interested in further information may write to Mr. Reis, Supervisor of Institutes, University of Nebraska, Extension Division, Lincoln 8, Nebraska.

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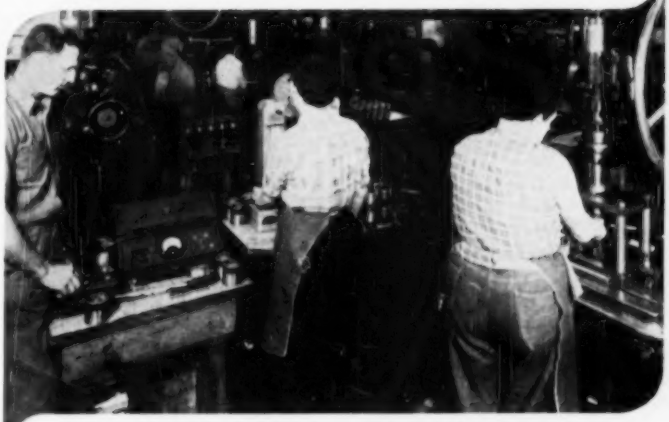

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AMERICAN SOCIETY NEWS

EXECUTIVE COMMITTEE—1952-1953

The first Executive Committee meeting was held in New York, Saturday and Sunday, Sept. 13 and 14, 1952. All of the new Regional Directors were present.

The Executive Committee of the Society is now complete and is constituted as follows:

S. S. Collier, President, *Chairman*
Arthur Bender, Vice President
R. S. Saddoris, Vice President
J. H. Toulouse, Vice President
E. B. Haden, Executive Secretary
W. R. Weaver, Junior Past President
P. A. Robert, Treasurer
M. E. Wescott, Chairman, Editorial Board
I. W. Burr, Acting Chairman, Editorial Board

Regional Directors—
E. E. Schiesel—New England
B. B. Day—Middle Atlantic
Leon Bass—Northern
Max Astrachan—Central
H. J. Becker—Midwest
D. L. Biggs—Western

The following major actions were taken.

Two new sections were admitted since the Annual Meeting, namely, Allentown-Bethlehem and Trenton. Both are located in the Middle Atlantic Region. This brings the total number of sections of the Society to 62. Groups in other areas are actively working on the organization of new sections. It is anticipated that before the year is over, the number of sections will be materially increased since the past growth of the Society clearly indicates that it has filled a need and has and will continue to contribute materially to industry.

A subsection of the Metropolitan Section has been organized in Long Island. Their first meeting was quite successful as evidenced by an attendance of approximately 135. The Society extends its welcome to the officers and members of these new sections and wishes them to call on us for any help that they may need in building a stronger section.

NATIONAL CONVENTIONS

Wade R. Weaver, chairman of the General Convention Committee, reported that plans for the Seventh Annual Convention are well advanced and that it is to be held in Philadelphia on May 27, 28 and 29, 1953, at Convention Hall. A tentative program has been prepared and is now being re-drafted into final form. Indications are that this Seventh Annual Convention will be even more successful than the previous ones.

The places and dates for future conventions are as follows:

1953—Philadelphia
1954—St. Louis
1955—New York

As yet no decision has been reached on the 1956 Convention city. The Society has received invitations from three sections. The General Convention Committee is reviewing these applications and will report their recommendations.

1952-1953 BUDGET ADOPTED

The tentative budget that was presented by the President and approved by the Executive Committee and Board of Directors at the Annual meeting in Syracuse was reviewed. A final budget was approved with minor changes based on an anticipated income of $63,310 and expenses of $60,696.

DUTIES OF THE VICE PRESIDENTS

The Society's Constitution was changed last year to provide for the election of more than one Vice President so that the President may have assistance in carrying out the affairs of the Society. It was voted last year that three Vice Presidents would be nominated and elected for the 1952-1953 term. The President has assigned to these Vice Presidents the following duties.

Vice President Arthur Bender will take over the duties of the past Vice President Simon S. Collier, and thus will be responsible for the coordination of the efforts of all of the general committees.

Vice President R. S. Saddoris will be in charge of the business management of the Society as it per-

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tains to our publications and advertising. His duties will include the supervision of all financial matters of the business office that has been set up by the Editorial Board in Milwaukee under the direction of Mr. G. R. Foster, Managing Editor.

Vice President J. H. Toulouse will continue to carry out his previous responsibilities in planning and coordinating the efforts of technical committees and divisions.

COMMITTEE APPOINTMENTS

New appointments have been necessary in order to fill the complement of all Committees to carry out the work for the coming year. The Society is very grateful to those members who by sincere and loyal service have aided the Society in continuing its growing importance.

The willingness of members of our Society to accept this responsibility has made it easier for the officers of the Society to carry out their duties and has been a very material help in building the Society on a firm foundation.

The following appointments have been made by the President and approved by the Executive Committee.

Shewhart Medal

A. L. Davis and E. H. Robinson have been appointed to fill the vacancies left by the retirement of P. A. Robert and C. E. Stines.

Brumbaugh Award

L. S. Eichelberger and Dorian Shainin have been appointed to fill the vacancies of C. R. Scott and H. H. Schaefer whose terms have expired.

Nominating Committee

The following is a complete list of the committee:

Wade R. Weaver, *Chairman*
Enoch B. Ferrell—
Middle Atlantic*
Wyatt H. Lewis—Western*
R. J. D. Gillies—Northern
L. Rosenblum—New England
Max Astrachan—Central
A. C. Richmond—Mid-West

* Since the term of office of these members as National Directors is still effective, they will continue to serve as members of the committee.

The Nominating Committee has received its instructions from the President and will prepare for the election of officers, including three Vice Presidents, for the ensuing fiscal year in accordance with the constitutional amendment approved by the Board of Directors and ratified by the members. The committee will report its recommendations to the Executive Secretary as prescribed by the constitution. This report will be published in the next immediate issue of IQC or the News Supplement, whichever printing deadline can be met, following receipt of the report by the Executive Secretary.

Examining Committee

Paul Olmstead has been appointed chairman to replace Professor L. Knowler who found it necessary to resign as chairman because of other duties. Professor Knowler will continue as a member of the committee.

Membership Committee

With the resignation of R. Inglis, E. T. Terhune has been appointed chairman. H. S. Bayer was appointed vice chairman to fill the vacancy left by E. T. Terhune.

Education and Training Committee

Professor J. A. Henry was appointed chairman to replace A. C. Richmond who retired. To fill the vacancy left by J. A. Henry, George W. McDermott was appointed vice chairman.

Publicity and Promotion

Frank Caplan was appointed chairman to fill the vacancy left by the resignation of J. F. Occasione.

Metals Technical Committee

A new committee has been organized and will be called Metals Technical Committee. The following appointments have been approved:

Chairman—
John W. W. Sullivan, American Iron & Steel Institute, 350 Fifth Avenue, New York City, New York

Vice Chairmen—
D. H. W. Allan, Steel Company of Canada, Ltd., Hamilton, Ontario, Canada
William P. Goepfert, Aluminum Company of America, Pittsburgh 19, Pa.

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Mason E. Wescott, our Editorial Chairman, receiving a scroll from Charles L. Matz. This was one of the high points of an appreciation and bon-voyage dinner given to Dr. Wescott in Chicago, July 16. He also received a watch and a piece of luggage, which he is using on his trip to India this fall.

Frank G. Norris, Wheeling Steel Corp., Steubenville, Ohio

Secretary—

W. T. Rogers, National Tube Company, Lorain, Ohio

The committee officers will have their first meeting on September 30, 1952 at which time subcommittee and special task forces will be set up and work assignments made. A tentative schedule has been prepared covering papers to be presented at the Seventh Annual Convention in Philadelphia in May, 1953. It is suggested that members of the Society interested in volunteering their services or submitting any suggestions communicate with the secretary of this committee.

BOARD OF DIRECTORS

The following is the composition of this board.

Society Officers

President: S. S. Collier
Vice President: Arthur Bender
Vice President: R. S. Saddoris
Vice President: J. H. Toulouse
Secretary: E. B. Haden
Jr. Past President: W. R. Weaver
Treasurer: P. A. Robert
Chairman, Editorial Board: M. E. Wescott
Acting Chairman, Editorial Board: I. W. Burr

New England Region

Albany: F. E. Satterthwaite
Boston: Louis Rosenblum
Buzzards Bay: Edward S. Rudnick
Hartford: Chester Hoffman
New Hampshire: Howard L. Bacon
Rhode Island: R. Shaw Goldthwait
Southern Connecticut: Ervin E. Schiesel
Western Massachusetts: Gerld B. Cassady
Worcester: Axel U. Sternlof

Middle Atlantic Region

Allentown-Bethlehem: Max Krissiep
Lansdale: Francis Henderson
Metropolitan: Enoch B. Ferrell
Philadelphia: Allen R. Crawford
Trenton: Vincent E. Pellegrino
Washington: Lt. Comdr. W. W. Kaufman

Northern Region

Buffalo: H. R. Bolton
Mid-Hudson: Donald G. Dunn
Montreal: B. H. Lloyd
Rochester: J. C. Warren
Southern Tier: Irvin C. Kepner
Syracuse: Leon Bass
Toronto: R. J. D. Gillies
Univ. of Western Ontario: M. Fred Kennedy
Utica: R. B. Griffith

Central Region

Birmingham: Winfred McCartney
Cincinnati: Henry J. Levin
Cleveland: S. C. Bates
Columbus: R. E. Wagenhals
Dayton: Max Astrachan
Erie: J. S. Zahniser
Georgia: John Reynolds
Greater Muskegon: Roland Lange
Huntsville: Verne H. Reckmeyer
Louisville: E. J. Zimny
Michigan: William H. Smith
Parkersburg: Eugene C. Mayo
Pittsburgh: W. P. Goepfert
Tennessee: David S. Chambers
Toledo: Nelson G. Meagley

Western Region

Los Angeles: W. L. Lewis
Mexico: Domingo M. Lopez
San Diego: I. Dagan
San Francisco: Dorothy L. Biggs
Seattle: Dr. Grant J. Butterbaugh

Midwest Region

Central Illinois: A. C. Richmond
Chicago: Henry J. Becker
Dallas-Fort Worth: J. C. McKelvain
Denver: Dale L. Lobsinger
Evansville-Owensboro: William E. Gibbons
Indianapolis: George W. McDermott
Iowa: Fred J. Halton
Milwaukee: Al Ceragioli
Minnesota: Philip O. Lysne
Muncie: D. B. Browne
North Eastern Indiana: Keith E. Ross
Racine: E. W. Solum
Rock River Valley: Roy Wylie
St. Louis: Paul K. Leatherman
South Texas: B. L. Cloud
Wichita: Earle Miller

DIVISION SET-UP

During the past year a plan was approved by the Executive Committee and Board of Directors of the Society to form divisions within the Society. The aim of a division would be to procreate interest in QC in its particular field. Membership in the division would be open to all members of the Society. J. H. Toulouse, Vice President in charge of divisional activities, is preparing the final draft of a constitution that will be used as a guide for the operations of any divisions that are set up.

The Textile Technical Committee, one of the original six technical committees was the first committee to request divisional status. This action was approved by the Society and the first meeting as a division was held at Clemson, S. C. on August 22-23. The following officers were appointed:

Chairman: G. M. Hailes
Vice Chairman: C. L. Adams
Secretary: J. H. Reynolds
Treasurer: D. S. Hamby
Trustee: J. H. Toulouse
Councilors: E. Rudnick
O. P. Beckwith
W. S. Smith

At the Annual Meeting of the Society in Syracuse the Board of Directors and the Executive Committee approved, in the budget for

1952–53, funds for the possible publication of two supplements to *Industrial Quality Control*. The first supplement entitled "Textile Division Supplement to Industrial Quality Control" was published in August and copies have been forwarded to members of the Society. This supplement contains the papers that were presented at the Clemson meeting.

The Chemical Technical Committee under the chairmanship of R. H. Noel has also petitioned for divisional status. Dr. Toulouse will work with this committee so that their petition can be formally approved after they have completed all the necessary steps required for formation of a division.

INFORMATION FOLDERS

The Information Folders covering the year 1952–1953 are in process of preparation and should be available by October 15. Sections should ascertain their needs and make requests to the Executive Secretary.

COOPERATION WITH THE GRAY IRON FOUNDERS' SOCIETY

Cooperation between the Gray Iron Founders' Society and ASQC has been requested. A committee consisting of Nelson G. Meagley, chairman, Allen Evans and Julian H. Toulouse was appointed and approved as a liaison group to work with a committee from this society to explore the possibility of cooperative effort.

CHEMICAL DIVISION

More than 75 members from 15 different chemical fields are looking forward to formal installation of the new Chemical Division soon. Several subcommittees guided by R. S. Bingham, Jr. now of Atlas Powder Company, Tamaqua, Pennsylvania, are completing details. They hope to obtain activation of the division at the Princeton Conference, December 5.

The Chemical Division will serve the needs of members working in the food, drug, fermentation, petroleum, papermaking, explosives, fertilizer, and other chemical process industries. Special symposia, publications, and other projects are planned to serve workers and to help the growth of statistical quality control in this field.

Charter members will be accepted up to the date of installation of the division. Annual dues will be $1.00.

Let these 3 OPTICAL AIDS answer your PRECISION PRODUCTION PROBLEM

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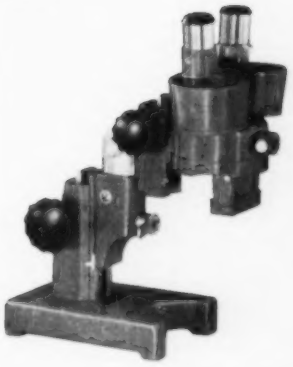

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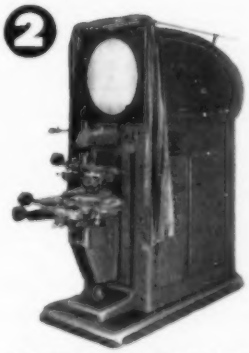

CONTOUR MEASURING PROJECTOR No other projector can match its accuracy: angular measurements to ± 1 minute of arc with a protractor screen, and direct linear measurements to ± .0001" over a range of 4" x 6" with the cross slide stage. Dimensions, angles, and profiles of production-run parts can be compared directly with a *traced outline* of the projected image of the master part, or with a large scale drawing superimposed on the screen. Inaccuracies are found quickly . . . simply. Write for Catalog D-27.

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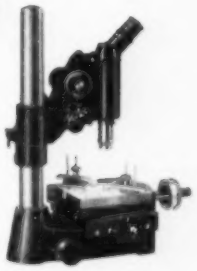

TOOLMAKERS' MICROSCOPE

This sturdy microscope gives you one inch linear measurements to ± .0001" and angular measurements (with protractor eyepiece) to ± 1 minute of arc. Operation is extremely *simple* and *fast*. Opaque and transparent objects of any contour can be measured. Catalog D-22.

WRITE for complete information on these three important optical aids designed to save you time and money. You may be paying many times over their moderate cost in lost time and rejects. Bausch & Lomb Optical Co., 79511 St. Paul St., Rochester 2, N.Y.

Bausch & Lomb *Quality Control* Instruments

Notify R. E. Burgess, Don Baxter, Inc., Glendale 1, California, if you wish to be enrolled. All members in good standing who are working in the chemical field are urged to join the Chemical Division now.

STANDARDS COMMITTEE

Dr. H. F. Dodge, chairman of this committee, has submitted, "Standard Definitions and Symbols for Control Charts" as the first standard published by the Society. A copy will be mailed to each member of the Society and extra copies will be available at a nominal cost.

NEXT EXECUTIVE COMMITTEE MEETING

The Executive Committee was invited to hold its next meeting during the Seventh Mid-West Conference in Indianapolis, Indiana. This generous invitation was accepted and the meeting will be on Saturday and Sunday, November 22 and 23, 1952.

CONTRIBUTIONS TO SHEWHART MEDAL AND BRUMBAUGH AWARD FUNDS

Many of the Sections have taken a very active interest in making certain that both the Shewhart Medal and Brumbaugh Award will have sufficient funds to insure that the Society may continue to use these two special awards for the recognition of outstanding work by its members. During the past year contributions have been received from the following:

	Brumbaugh	*Shewhart*
Middle Atlantic Conference	$ 75.00	$ 75.00
Sixth Midwest Conference	100.00	
St. Louis Section	25.00	25.00
Rochester Section	100.00	
Hartford Section		100.00
Metropolitan Section		50.00
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GETTESGOTE ADDRESS
(With apologies to Abe Lincoln)

One score and eight years ago, Walter Shewhart brought forth on this skewed universe a new degree of freedom, conceived out of confusion and dedicated to the proposition that figures could lie, and vice-versa.

Now we are engaged in a great mass of biased estimates, testing whether one statistic, or any statistic, so confused and so out of control, can long endure. We are met in a great center of that confusion. We have come to dedicate a large portion of our interaction to a final resting place with those who spend their time in X and other bars.

It is altogether without "t" significance that we should do this. But in the replication sense, we cannot partially correlate, we cannot backsolution, we cannot sigma these data. The staff, their Chi-square and their analysis of variance, who scattergrammed us here, have gone far beyond our poor power to divide and multiply.

Our employers will little note nor long remember what we do here, but their Null Hypothesis will never agree with what we say here. It is for us, poor statisticians, rather to be devoted here to the mean square deviation which our bowls have thus far so regularly produced. It is rather for us to be dedicated to the coefficient of alienation remaining before us—that from these sequential samples we take increased columns and rows to the range and attributes remaining; that we here highly resolve to confound our primes and averages; that these grouped data, under class intervals, shall give us more variable constants; and that correlation of the Beta functions, by the Latin squares, and for the standard errors, shall not vanish in our calculating machines.

Prepared and presented by Dr. Julian Toulouse as part of the class dinner program, Purdue Advanced SQC Course, Purdue University, June, 1952.

CONSULTING SERVICES

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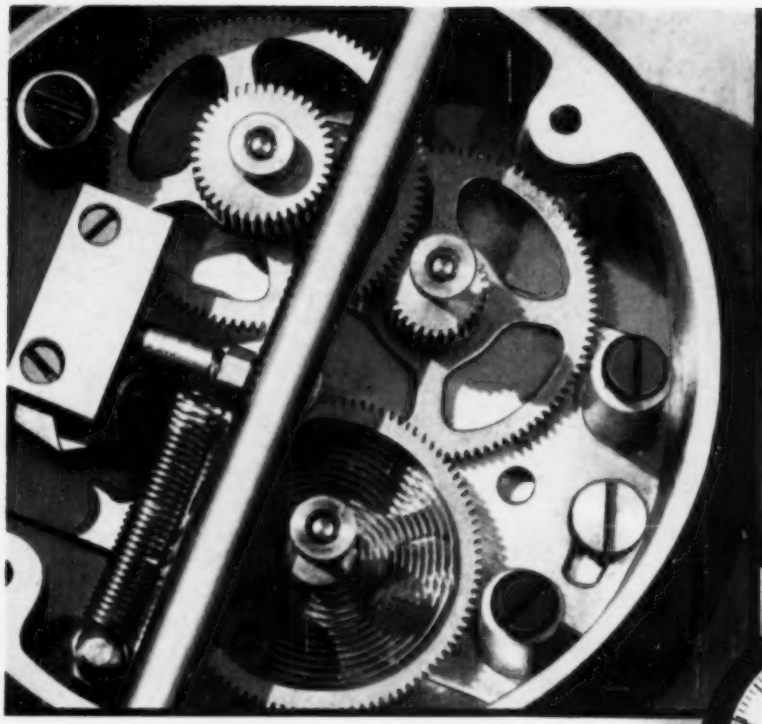

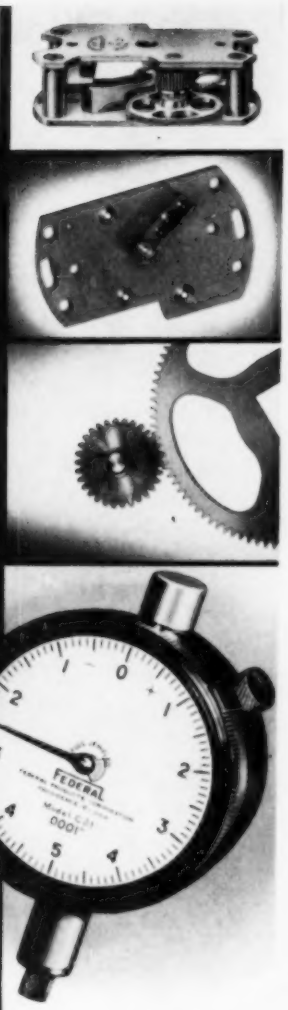

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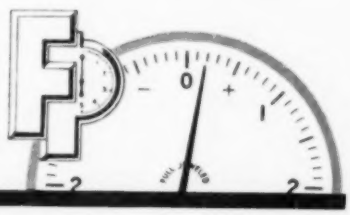
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